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The INSTITUTION *of*
PRODUCTION ENGINEERS

JOURNAL

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PLASTICS FOR THE ENGINEER

by I. W. A. Kirkwood, M.I.E.E., M.A.I.E.E., and
P. D. Richie, B.Sc., Ph.D., A.I.C.

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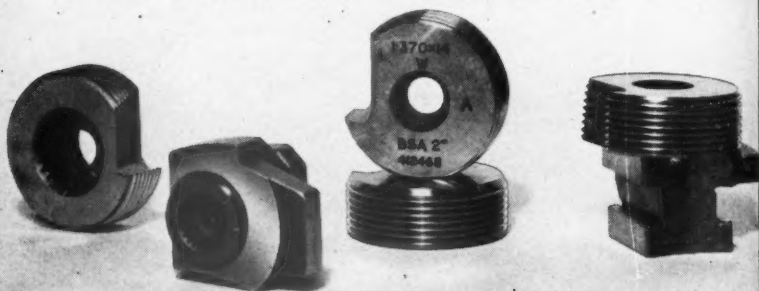# INDEX TO ADVERTISEMENTS

As a war-time measure the advertisement section of this Journal is now pub-lished in two editions, A and B. Advertisers' announcements only appear in one edition each month, advertisements in edition A alternating with those in edition B the following month. This Index gives the page number and edition in which the advertisements appear for the current month.

The fact that goods made of raw materials in short supply owing to war conditions are advertised in " The Journal" should not be taken as an indication that they are necessarily available for export.

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INSTITUTION NOTES

April, 1944

May Meetings.

6th Yorkshire Graduate Section. The Annual General Meeting and "Brains Trust" will be held at the Great Northern Hotel, Leeds, at 2-30 p.m. It will be preceded by a luncheon.

12th A Meeting is being held for Members of the Institution at the Institution of Civil Engineers, Gt. George Street, Westminster, S.W.1. at 7-0 p.m. Professor Postan, Professor of Economic History at the University of Cambridge, will lecture on " Post War Reconstruction in the Engineering Industry."

13th Yorkshire Section. A Joint Meeting with the Institute of Industrial Administration will be held at the Hotel Metropole, Leeds, at 2-15 p.m. when W. Puckey, Esq., M.I.P.E., F.I.I.A., will read a paper on " Organising for Production."

20th Nottingham Section. Annual General Meeting, University College, Shakespeare Street at 2-30 p.m.

May Committee Meetings.

13th Joint Examination Board. James Watt Memorial Hall, Birmingham at 2-30 p.m.

16th Education Committee Meeting at Queens Hotel, Birmingham, at 10-0 a.m.

16th Membership Committee Meeting at Queens Hotel, Birmingham at 12-30 p.m.

19th London Section Committee Meeting, Institution of Civil Engineers, Gt. George Street, S.W.1., at 12-30 p.m.

19th Annual General Meeting of the London Section, Institution of Civil Engineers, Gt. George Street, S.W.1., at 12-30 p.m.

19th Finance and General Purposes Committee at 1-0 o'clock.

21st Research Finance Committee, Black Boy Hotel, Nottingham, at 5 o'clock.

21st Research Management Committee, Black Boy Hotel, Nottingham, at 6 o'clock.

22nd Research Management Committee at Loughborough at 10 o'clock.

26th Special Meeting of the Finance and General Purposes Committee at 10-30 a.m.

The Technical and Publications Committee meets at Institution Headquarters every Wednesday at 5-30 p.m.

The Graduateship Examination, 1944.

The Graduateship Examination will be held on Thursday and Friday, the 4th and 5th May, and Monday and Tuesday, the 8th and 9th May respectively. Individual candidates will be notified in due course of the name of the Technical College at which they are to take the examination.

The Lord Austin Prize.

As announced in the previous journal, the award of the above prize has been in abeyance since 30th June, 1939. It has been decided, during the current year, to reinstate this award which will be open to all Graduates who have entered the Institution since the above date.

For this year only, two awards will be made on the following basis :—

(a) One prize for Graduates who have passed the Institution Examination held, or who have been accepted as Graduates by virtue of exempting qualifications during the period 1st July, 1940 to 30th June, 1943, including the 1943 Graduate Examination.

(b) One prize for Graduates who have entered the Institution by virtue of exempting qualifications since 1st July, 1943 and to those candidates who are entering for the Graduate Examination of the Institution to be held in May this year.

In succeeding years the Award will be made on the basis of (b) for each Institution year, which commences on 1st July, and ends on 30th June.

The Award will be granted to the Graduate who submits the best essay on one of a list of subjects submitted. This essay does not form any part of the Graduateship Examination but is set for the purpose of the Lord Austin Prize only.

The conditions governing this Award, and the necessary application forms, will be forwarded to all Graduates entitled to compete on application to Institution Headquarters, 10, Seymour Street, London, W.1. The latest date for receiving applications is 10th June, 1944.

Personal Column.

Mr. H. W. BOWEN, M.I.P.E., President of the London Section, has been elected to the Board of The Gramophone Co. Ltd., and the Columbia Gramophone Co. Ltd. We extend our sincere congratulations to him.

Mr. J. A. HANNAY, M.I.P.E., has retired from the position of Production Manager in the Austin Motor Co. Ltd. Mr. Hannay

was Chairman of Council in the early days of the Institution. We sincerely trust that Mr. Hannay will enjoy the best of health during his well-earned retirement.

Mr. J. L. MUNN, M.I.P.E., has been appointed Works Manager in the Austin Motor Co. Ltd. Mr. Munn is the present President of the Birmingham Section.

Obituary.

We deeply regret to learn of the deaths of the following members of the Institution :

Mr. H. S. Locker, M.I.P.E.   Mr. A. E. Cutler, A.M.I.P.E.

Both the above named members were members of the London Section.

TECHNICAL BOOK INFORMATION

British Standard 308, 1943.

The attention of members is drawn to the British Standards Institution publication entitled " Engineering Drawing Office Practice " (B.S. 308, 1943). This booklet deals with the standardisation of drawing office practice and we commend it to our members for their perusal.

Book Review.

Metals in the Service of Man, by William Alexander and Arthur Street.   Pelican Book Series.

This book is very interesting and gives a mass of information in simple language.   It covers a fairly wide field in the science of metals and should be very helpful to many whose knowledge is very limited in this direction.

A. ROBERTS, (*Associate Member*).

PLASTICS FOR THE ENGINEER

Paper presented to the Institution, N. Eastern Section,
on 21st. October, 1943, by I. W. A. Kirkwood, M.I.E.E.,
M.A.I.E.E.,* and P. D. Richie, B.Sc., Ph.D., A.I.C.†

Introduction

No technical advance during the past few years has been more
spectacular than the rapid expansion of the use of plastics ; and
not only the technician but also the casual layman has in spite of
himself become increasingly plastics-conscious. In practically all
branches of engineering ; in many phases of the aircraft and other
war industries ; in the building, decorative, clothing, and luxury
trades—in these and numerous other aspects of modern life,
plastics have come to stay. Their future developments and reper-
cussions we can only dimly foresee.

One inevitable consequence of the extreme rapidity and apparent
complexity of these developments has been a marked time-lag in
the spread of exact knowledge of plastics among any but immediately
interested specialists. Even among those upon whose profession
or interests the impact of the new materials has already been most
felt, there are comparatively few who realise fully what a plastic
is, and what are its possibilities, its limitations, and its economics.
Even in peace-time there would still be few with sufficient leisure
to achieve the joint mastery of physical, chemical, and engineering
sciences necessary to answer completely the question, " How do
these new ideas and materials affect my work ? "

There is, then, a gap between the rapid advance of research
and its pursuit by the technical education necessary for its full
exploitation. This paper (presented for convenience in two parts)
is a bold attempt to bridge the gap at a few of the main points
essential to the engineer or designer with an interest in but no
specialised knowledge of plastics.

*Senior Insulation Engineer and †Chief Chemist, both of the Reyrolle
Technical Research Department.

PART I

The Physical and Chemical Nature of Plastics, and their General Classification

By P. D. Ritchie, B.Sc., Ph.D., A.I.C.

General

The engineer is often faced by unfamiliar terms in modern technical literature. What is polymerisation ? What is a polymer ? Is a plastic the same thing as a synthetic resin, and, if so, how does it differ from a natural resin ? How is a moulding powder related to a plastic, and what is the difference between a thermo-plastic and a thermo-hardening moulding powder ? In this first part of the paper the general background of the subject of plastics will be outlined, and some at least of the above specific questions answered. Further, since the paper is addressed essentially to non-chemists, all but the more readily understood chemical terms will be avoided. It must be realised that some simplified chemistry is inevitable ; but emphasis of the chemical aspect will be avoided when this can be done without giving a definitely incorrect picture.[1]* Indeed, several of the statements of rather complicated fact may be criticised by chemists as over-simplified : and some broad generalisations that will be made are perhaps not yet universally accepted. Nevertheless, the general picture of modern industrial plastics that will be presented will be very substantially correct.

Plasticity, Softening-Point, and Melting-Point

According to classical ideas, a substance is said to be plastic if it is capable of taking up a new shape when pressure is applied to it, and of retaining that shape when the pressure is removed. This is known as *plastic deformation*, as distinct from *elastic deformation* where the original shape is regained when the pressure is removed. Potter's clay is perhaps the best known example, being plastic even when cold ; and pitch, many waxes, and familiar natural vegetable resins like amber and cobbler's rosin, have a similar property when warmed up, softening gradually to a consistency suitable for moulding. Even a heated metal has some plastic properties, though it must not be assumed that the cause of plasticity is exactly the same in all these examples.[2]

*This and subsequent similar references are to Appendix A, item (1) of which indicates a few publications that may be studied by those who desire to go into the chemical aspect in greater detail.

Pure substances have, in general, sharp melting-points, and a strong tendency to crystallise on solidifying again. Mixtures, on the other hand, especially those containing many closely-related components, soften slowly and indefinitely over a fairly wide temperature-range, and very often do not crystallise readily on cooling again, simply remaining in an amorphous, resinous, or glassy condition when they solidify. The reason why pitch softens slowly, and does not melt suddenly into a liquid at a definite temperature like solids such as ice, is that it is not a pure substance but an intimate mixture of a whole range of closely related compounds. The same applies to ordinary commercial paraffin wax, vegetable resins, and to many other mixtures of a similar type. This is well-known in chemistry, and will be referred to again.

Such materials as pitch and the natural vegetable resins, then, are natural plastics. There are also many simple commercial synthetic products of a physically rather similar type, such as Seekay wax and the Aroclors, which melt eventually into true liquids of fairly low viscosity, and might logically be designated *synthetic resins*. The group of industrial materials known nowadays by common consent as synthetic resins and plastics is, however, composed for the most part of rather more complex materials, which do not usually reach a truly liquid stage on heating, though they may soften to a viscous, rubbery, or semi-fluid state. They are, in general, quite amorphous, and have no apparent crystalline structure, whereas paraffin wax and Seekay wax are really micro-crystalline, and should only be considered as plastics with this reservation in mind.

No attempt will be made here to define the foregoing rather loose conception more rigidly, as it seems almost impossible to frame a definition absolutely free from exceptions and ambiguities, owing to the extraordinary variety of the materials dealt with by the plastics industry.* (Rubber, for example, is excluded by many from the plastics classification, although it can be included very logically and convincingly.) An attempt will be made, rather, to show how closely a modern industrial plastic is related to materials one handles every day without considering them as plastics—glass and pottery ; wood, silk, wool, and cotton ; leather, meat, muscle, oil-paints ; and many others. The chemistry of most synthetic plastics is now fairly well understood, and, though complicated

*The following tentative definition, adapted from that proposed by Randolph at an A.S.T.M. Symposium in 1938, is fairly comprehensive, but clumsy, and may serve to indicate the difficulty of formulating a neat yet exact definition :

"A *plastic* is a material which consists of, or contains as its essential ingredient, an organic or inorganic binder, and which, at some stage in its manufacture, or in the fabrication of articles from it, is capable of being shaped by flow while in a plastic or liquid condition, and is thereafter capable of being brought to a relatively rigid condition."

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in detail, has simple basic principles readily understood by any technical man, chemist or otherwise. It will be shown how, by using one basic conception, practically all the common everyday materials just mentioned can be correctly correlated with industrial plastic materials such as Bakelite and artificial silk.

Polymerisation : Chain-Molecules and Thermoplasticity

Most people know in a general way what an atom and a molecule are. A molecule of any given compound is the smallest possible particle or unit into which the compound can be divided and yet retain its chemical properties unchanged. It is a group of atoms bound together by chemical affinity : and if it is split up further the resulting smaller particles no longer show the chemical properties of the original molecule. The new particles may be either individual atoms or molecules different from and smaller than the original. Generally speaking, the molecules of any one material have no chemical affinity for each other, though they are of course held together by physical cohesive forces such as those which keep an iron bar rigid and prevent it from disintegrating into a mass of separate particles. But there are substances whose molecules contain what will, for the purposes of this paper, simply be termed linking groups. These tend to catch on to, and adhere chemically to, similar linking-groups in other identical adjacent molecules, with the result that two, or twenty, or several thousand of the original molecules may link together chemically to form very much larger molecules, with new and novel properties quite different from those of a mere mixture of small molecules loosely attracted by physical cohesion. Here, all the units that link together are the same—not as in most simple chemical reactions, such as the union of hydrogen and oxygen, where two different materials combine to form water.*

The simplest way to represent such a linking is by the formation of long chains—a simple addition process, repeated many times, whereby two molecules link together in line, pick up another at the end of the chain, and so on (see Fig. 1). A great volume of experimental evidence shows that such linear chain-molecules, essentially one-dimensional, are typical of the natural fibrous cellulosic materials such as wood and cotton, and also of raw rubber, muscle, silk, wool, and hair. Some of these have been synthesised, or partially synthesised, in the laboratory. It has, for example,

*The non-chemist must, unfortunately, be asked to take for granted the existence of such linking-groups in some molecules and their absence from others. To go into the exact nature of such groups would be far beyond the scope of this paper : but chemists will reconise in them the familiar double bonds, the reactive *ortho* and *para* hydrogen atoms of the phenols, and the hydroxyl, carboxyl, amino, and carbonyl groups of organic chemistry.

been possible to build up at least in part the very long chains that form silk and similar protein materials. The natural molecules of these substances were until recently much larger than anything produced in the laboratory in imitation, though the new Nylon plastics have a distinct chemical resemblance to natural silk : and it has also been possible to synthesise a reasonably good
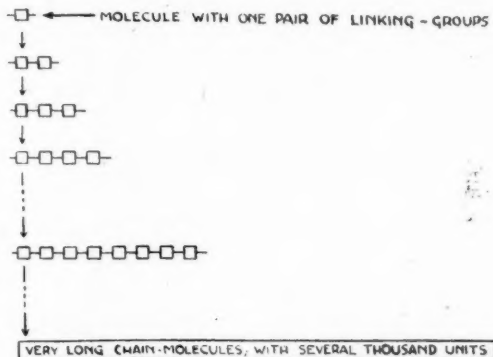
FIG. 1.   FORMATION OF CHAIN-MOLECULES.

imitation of the long chain of carbon and hydrogen atoms constituting the rubber molecule, which will be dealt with later on.[3] But in no case yet investigated are we so delicately efficient as the living tissues in synthesising such natural chain molecules. Although, for example, we know what the simple unit member of the cellulose chain is like, and can prepare it as an individual, we cannot do much towards pursuading it artificially to link with its neighbours.

This linking together of multiples of the same unit molecule is known as *polymerisation*, a term at least vaguely familiar to every technical man : and the resulting long-chain material is known as a *polymer* of the simple starting material or *monomer*. Now, although we have not had much success in duplicating synthetically the natural chain-molecules, we have at least been able to produce, first in the laboratory and later on an industrial scale, many entirely new chain molecular products of a very similar pattern. Some are quite different from any natural product and are wholly synthetic, whereas others are useful artificial modifications of already existing natural chain-molecular products—for instance celluloid, which is got by a chemical treatment of natural cellulose itself.

By way of a concrete example, let us deal at some length with the materials known as styrene and polystyrene. They form an extremely simple and typical case, which will give a good idea of the whole subject, and which has been worked out in exhaustive detail. [4] Further, polystyrene is well worthy of study as a plastic of growing industrial importance, now being manufactured in this country under the trade-name Distrene.

Styrene is a colourless liquid, similar to benzene, and when heated for a long time gradually thickens to a viscous syrup and finally hardens to a clear glassy solid known as polystyrene. This name is based on the now generally accepted fact that the individual molecules of the liquid styrene, which each contain one pair of linking-groups, link up with one another into chains under the influence of heat. The chains are relatively few while the material is still in the syrupy stage ; but as more and more molecular chains begin to form in the heated mass, the syrup becomes progressively more and more viscous, until finally, when there are virtually no more unlinked single molecules left, the materials is so viscous that it is no longer liquid at all, but solid. Notice that nothing has apparently taken part in the reaction but styrene molecules and that nothing but polystyrene is produced, and notice, also, three fundamental facts, to which attention will be directed again later on. The first is that if we heat the solid product it softens : and, though it does not melt to a true liquid, it becomes sufficiently plastic to be pressed, moulded, or extruded into various shapes, which it retains on cooling. This can be repeated again and again, the polystyrene undergoing no further chemical change ; and it is this completely and permanently reversible moulding-cycle that is the accepted criterion of a *thermoplastic* material, of which celluloid, polystyrene, and the transparent plastic known as Perspex, are typical examples. The last-named is a solid polymer produced by the polymerisation of a liquid monomer, on exactly the lines indicated for polystyrene itself. One sometimes hears thermoplastics described by the alternative names *thermo-softening* or *non-heat-convertible*, the latter being an American term whose meaning will become apparent later on. The second of the three fundamental facts is that polystyrene is soluble in some solvents— not instantly, like washing-soda in hot water, but slowly and with swelling, like glue in hot water. And the third fundamental fact is simply that the molecules are long chains, not necessarily following geometrical straight lines, but still essentially one-dimensional.

Before leaving the subject of styrene, it will be useful to consider a simple graph, based on data by Scholz and Husemann (see Fig. 2), which illustrates a very important point, namely that the length and the weight of the resulting chain-molecules depend on the temperature of polymerisation.

PLASTICS FOR THE ENGINEER

The molecular weight is here, of course, the weight of one single
styrene unit (104 times that of an atom of hydrogen, the lightest
of all the elements) multiplied by the number of links in the chain.
As the graph shows, on heating styrene at fairly high temperatures
(about 200-250°C.), which induces rapid polymerisation, the
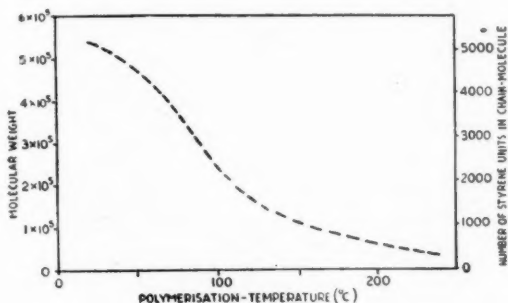
FIG. 2.   MOLECULAR-WEIGHT/POLYMERISATION-TEMPERATURE CURVE
FOR STYRENE.

molecular weights are of the order of 50,000—that is to say, the
chains are some 500 styrene units in length, which corresponds
to a relatively low viscosity.   But, if the polymerisation is done
over a very long period slowly, at approximately atmospheric
temperature, the chains grow to relatively enormous lengths of
5,000 styrene units or more.   The molecular weight is now of the
order of half a million, and the viscosity is correspondingly high.
In other words, it is possible, under suitable manufacturing
conditions, to produce a graduated range of polystyrenes of various
properties, suitable for particular purposes, and we are thus not
limited to one method of polymerisation and one end-product
only.   Heat, for example, is not the only influence that can cause
liquid styrene to polymerise.   The presence of some salts induces
rapid polymerisation, giving rise to short chains and low viscosity :
and exposure to ultra-violet radiation can also start the process.
Further, styrene polymerises most readily when in contact with
oxygen or oxidising agents, and can be preserved for a very long
time without polymerising if such materials are rigorously excluded

It should be clearly noted that when we speak of a molecular
weight of, say, 100,000 we do not imply that each chain in the
mass has precisely this molecular weight.   The chain-molecules
vary over a relatively short range of lengths around it as a mean
value, and the mass is therefore an intimate mixture of closely

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related materials, which, as in simple plastics like pitch and paraffin wax, perhaps accounts for the gradual softening on heating and the absence of a sharp melting-point. When this point was touched upon a little earlier, it was said that some natural materials like pitch on the one hand, and some simple synthetic plastics such as Aroclor on the other hand, could eventually be melted to true liquids after the initial vague softening point ; and this difference from the long-chain polymerised materials appears to be due to the fact that these simpler plastics are not polymerised materials but mixtures of fairly simple and small unit molecules, which possess no linking groups. In other words, they are plastics, but not polymers. It should therefore be emphasised that thermoplastic materials fall into two groups—one in which the components of the mixture are relatively long-chain molecules ; and a second in which the components may be fairly short-chain molecules, or even small molecules not within the category of chain-molecular polymers at all.

Thermo-Hardening Materials : Cross-Linked Molecules

Let us now pass on to another class of materials—the *thermohardening* or *thermo-setting* plastics. Here we are on more familiar ground ; for by far the best-known member of this class is Bakelite, the " Grand Old Man " of synthetic resins, with which everyone is more or less familiar.

There is nowadays an unfortunate and confusing tendency for the layman to use the term Bakelite when describing almost any modern moulded plastic product. " Bakelite," however, is a registered trade-mark, which strictly speaking must be applied only to the products of one particular manufacturer, in one particular group of synthetic resins—the so-called phenol-formaldehyde, P.F., or phenolic group.* It has none the less gradually been fairly widely adopted as a convenient type-name to cover the phenolic group in general, and has indeed almost attained scientific text-book status in this connection, familiarity having bred such contempt that Bakelite very frequently appears as bakelite.

As their name suggests, these P.F. materials are made by combining the common raw materials known as phenol (that is, carbolic acid) and formaldehyde (that is, formalin). If we use as our starting material a mixture of phenol and formaldehyde molecules in approximately equal numbers and apply heat, the first stage is, as before, the formation of linear chain-molecules, which are relatively short this time—probably some 5 to 10 unit molecules in length at the outside. The product is usually called a resol,

*The manufacturer in question has, however, recently added a polystryene plastic to the materials marketed under this trade-mark.

or the A-stage of the phenolic resins. Here, it should be noted, the units comprising the chain are of two types, namely phenol and formaldehyde ; but since they initially link up in a more or less regular alternate sequence they may be considered as giving chains essentially similar to those of thermoplastic polystyrene. But there is an important difference. The styrene molecule, as already indicated, contains only one pair of linking-groups,
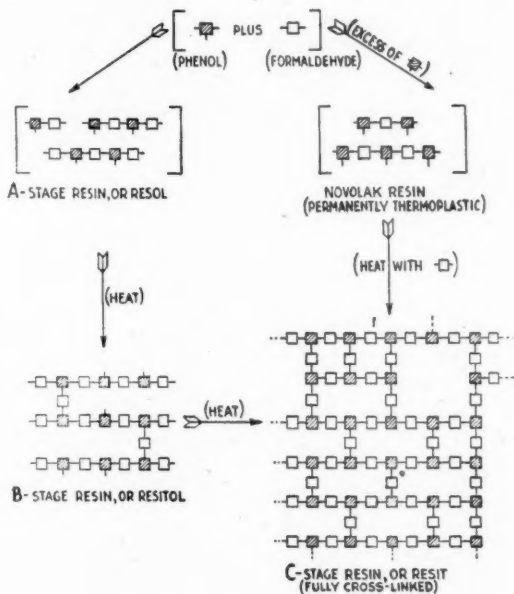
FIG. 3. FORMATION OF PHENOL-FORMALDEHYDE PLASTICS.

and can therefore only link up with neighbouring molecules into a chain ; whereas the phenol units in the phenol-formaldehyde chain have other potential linking groups present, over and above those utilised in forming the primary chain-molecules, and can start side-branches from the main chain by linking up with more formaldehyde units (see Fig. 3). On heating the A-stage of the phenolic resins, these free linking-groups begin to react with linking-groups in adjacent resol molecules, increasing the length of the original chains, and linking together neighbouring chains

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at a few points here and there, the number of such cross-links or bridges increasing as the heating is continued. This second stage is called a resitol, or the B-stage, and is rather loosely defined ; and the process is often known as curing, or, less correctly and frequently, as " bakelising." As can be imagined, the linking up goes on in all directions throughout a mass of random chain-molecules ; and by the time virtually all the linking-groups within the mass have become attached to one another, and the resin is fully cured, a polymer is left consisting not of a mass of separate linear chains but of an intricate and highly irregular three-dimensional mesh of interlacing cross-linked branches—the final or C-stage of the phenolic resins, often termed a resit. And here, once more, three fundamental facts may be pointed out, for comparison with those given for polystyrene. First, C-stage phenolic resin is no longer appreciably softened by the action of heat : the moulding-cycle is therefore an irreversible one, and a phenolic resin is a *thermo-hardening* plastic, sometimes called in America *heat-convertible* in contrast to the term *non-heat-convertible*, applied, for example, to polystyrene, with its reversible moulding-cycle. Secondly, a fully cured phenolic resin is insoluble in all the usual solvents, except those which, like strong acids, destroy the material entirely. And, thirdly, the molecules are now no longer even approximately linear chains, but intricate and irregular three-dimensional meshes, which might be compared to a piece of felt rather than to a regularly-woven textile fabric. [5]

An understanding of these two main divisions of polymerised substances covers the basic essentials of the plastics industry, from which there can be developed the relationship of synthetic plastics both to the natural long-chain molecules like cellulose and rubber and to man-made products like glass and pottery, which will be dealt with later.

A fourth difference between the two divisions might also be mentioned here very briefly, namely that the linking-groups in styrene are different in their action from those which link together phenol and formaldehyde into phenolic resins. In the former nothing is produced during polymerisation except polystyrene : whereas in the latter a molecule of water is split off and liberated every time a phenol linking-group becomes attached to a formalde-hyde linking-group during polymerisation. This is known chemi-cally as a condensation, although for the purposes of this paper there is no need to subdivide polymerisation processes into groups that are only confusing without some knowledge of chemistry. The point will therefore not be laboured. It will be shown, how-ever, in the second part of the paper that the electrical properties of phenolic resins are in general inferior to those of polystyrene ; and the fourth difference has been referred to because this electrical

inferiority is very probably due in part to the unavoidable trapping of traces of liberated water in the meshwork of the phenolic resin molecules as they progressively link together—a thing quite impossible in the polymerisation of styrene.[6]

Returning, now, to the A-stage resins, it is important to note that before they are heated for a fairly long period to link the chains together into a mesh-work they are actually thermoplastic and soluble in, for example, methylated spirits. Even when the original short chain-molecules have begun to link together to form the B-stage, the mass still softens on heating, and can still be dissolved, though not nearly so readily. If, now, we visualise the final or C-stage as a mesh-work of the relatively large phenol molecules cross-linked by bridges consisting of the smaller formaldehyde molecules, an interesting deduction can be made. It is reasonable to suppose that if we start with a pronounced excess of phenol over formaldehyde molecules, there may be insufficient of the latter to cross-link the final cured resin into a completely non-thermoplastic mass. Actually it has been found that with such a reaction mixture short chain-molecules are once more formed, rather similar to those of the A-stage already described. But in this case all the formaldehyde molecules are very soon used up in actually linking the phenol molecules together into a chain : there are no more left over in the mass to act as bridges between the chains themsleves, and we therefore find that the product from such a reaction mixture is permanently thermoplastic and soluble, just like polystyrene, and is not thermo-hardened into anything corresponding to the B and C stages on heating. Such resins are called Novolaks—once more, a trade-name that has been slowly absorbed into the literature.

If, now, pursuing this idea logically, we intentionally add to a Novolak an amount of formaldehyde sufficient to make up the above-mentioned bridge deficiency, the mixture can be thermohardened just like an A-stage resin, the freshly added formaldehyde acting as bridges between the adjacent short chains in the usual way. The whole scheme is summarised in Fig. 3, all molecules being shown two-dimensionally only, for convenience.

It should finally be emphasised that, just as we can control the properties of polystyrene by varying the conditions of polymerisation, so also we can control the properties of phenolic resins over a very wide range. For example, by slightly varying the ratio of phenol to formaldehyde in the original reaction mixture, or by replacing part or all of the phenol by other bodies of a similar chemical type, such as those known as cresols, plastics can be produced whose curing-time varies markedly, and which can therefore be adapted to many different moulding purposes.

Intermediate Co-Polymers

By now it will have been realised that the linear chain-molecules of the thermoplastics, and the cross-linked molecules of the thermo-hardening resins, should theoretically form the two extremes of a whole series of intermediate molecular types, graded according to the number of bridges or cross-links in the mass. Returning to styrene for a moment, it will be remembered that the styrene molecule has only one pair of linking-groups, which dictates that it shall polymerise in chain-form only. There is, however, a material known as divinyl benzene, very closely akin to styrene, but possessing two pairs of linking-groups per molecule, and hence capable of polymerising to a three-dimensional cross-linked synthetic resin. What will happen, now, if a small amount of this is mixed with a large excess of styrene, and the mixture polymerised by heat ? Actually, this was done by Staudinger in a very elegant series of experiments, and it was found that the small amount divinyl benzene simply linked together the long polystyrene chains into a rather loose three-dimensional network. Since, obviously, one small cross-link can bind together two large chain-molecules, even though the latter may each contain some thousands of basic styrene units, a very minute proportion of divinyl benzene might theoretically be sufficient to double the molecular weight and otherwise influence significantly the properties of the resulting polymer ; and in practice Staudinger found that one molecule of divinyl benzene in 10,000 to 50,000 of styrene is sufficient to render the final mixed polymer, or co-polymer, as such a hybrid is some-times called, markedly less soluble than pure polystyrene. [7] If the proportion of divinyl benzene—that is to say, the number of cross-linkings or bridges—is increased, the solublility of the resulting polymer decreases still more, although a large measure of thermo-plasticity is still retained. Eventually, at the other end of the scale. if practically pure divinyl benzene is polymerised, the product is now entirely three-dimensional like a cured phenolic resin, is softened by heat only with some difficulty, and is quite insoluble, though it swells slightly in some solvents.

The exact physical nature of any cross-linked polymer depends of course not only upon the number of bridges but also upon their chemical nature and that of the chain-molecules they are linking together ; and thus we find materials like ebonite—which will be dealt with later—where the cross-links are sufficiently numerous and strong to render the polymer insoluble, but where there is nevertheless still a good deal of thermoplasticity. Actually the effect of cross-linking is usually most apparent in the reduced solubility of the final product ; the accompanying reduced thermo-plasticity only becomes of fundamental importance in special

cases, for example in Bakelite itself. There is perhaps more logic in the American term heat-convertible than in the term thermo-hardening, which emphasises only one aspect of the conversion, and that not necessarily the most striking.[8]

It is interesting to reflect that in a fully cross-linked polymer there should theoretically be no clear-cut boundaries between molecule and molecule in the ordinary chemical sense, and that the
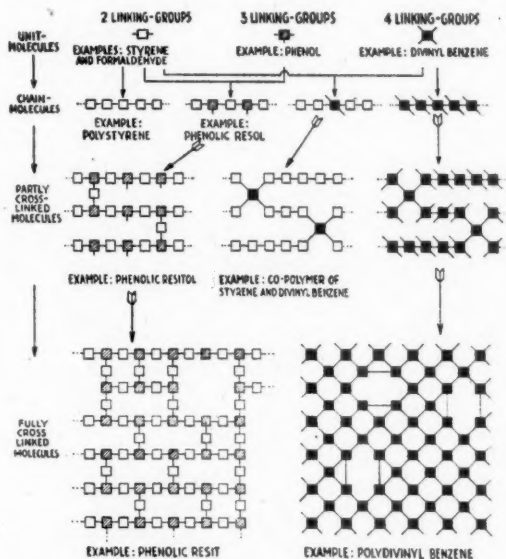
FIG. 4. VARIOUS DEGREES OF CROSS-LINKING IN TYPICAL PLASTICS.

whole polymerised mass should be interlocked into one gigantic molecule. But for one reservation this might well be true. It can be shown that even in a so-called fully cured phenolic resin an appreciable number of the potential linking-groups are locked into such positions by the gradual thermo-hardening of the mass that they are too far from any other free linking-group for inter-reaction to take place. In other words, they are left permanently unlinked : and the meshwork is not geometrically regular in its finer structure, but contains gaps, and unattached links, and small quantities of trapped water and other foreign matter, so that it is at least partially divided into separate cross-linked aggregates.[9]

Fig. 4 summarises what has just been said. It must be remem-

bered that the cross-linked polymers are actually three-dimensional, though for the sake of simplicity they are shown in the figure as two-dimensional only, and also that although the diagrams are strictly rectilinear the actual molecules probably have a rather random orientation, especially in the cross-linked forms. An attempt has also been made to show, in a purely diagrammatic way, the slight irregularities and gaps believed to exist in three-dimensional polymers.

A mere mechanical analogy is sometimes rather misleading in explaining a chemical phenomenon : but perhaps one might be useful here. If a bundle of lengths of thread more or less parallel to one another is immersed in water, they tend to float apart. This corresponds to ordinary polystyrene, where the chain molecules allow the solvent to penetrate into the bundle, swelling it, and eventually causing the chains to disperse uniformly into the solvent. If, however, the long threads in the bundle are fastened together at intervals by short cross-links of thread, and the bundle is then placed in water, it becomes loose and swells up, but the individual threads, being tethered to one another, are not entirely free to float away. This corresponds to the intermediate co-polymer of styrene and divinyl benzene described above. Finally, if the threads are linked together across and across, again and again, by little thread cross-linkings, the result is a much more coherent mass, which does not float apart into its component threads on soaking, and is more mechanically rigid that the bundle of unlinked threads, thus simulating polymerised divinyl benzene.

Moulding-Powders : Moulding Methods

A brief discussion of what are known as moulding-powders may suitably be included here. Phenolic resin moulding-powders, which have a very wide application nowadays, are made by compounding an inert filler, such as wood-meal, with a Novolak resin mixed with a complex material yielding formaldehyde bridges on heating. Such powders, when compressed in a hot mould, soften and flow sufficiently to fill the mould accurately, just as true thermoplastics like polystyrene do ; but on continuing the heating they gradually harden up by cross-linking into the C-stage, and are not softened again even by strong heating.

A somewhat similar sequence holds for other thermo-hardening plastics, such as the urea-formaldehyde or U.F. materials, which may be recognised under trade-names such as Beetle, Scarab, and Pollopas moulding-powders. Here, the intial basic units—urea and formaldehyde—first of all link together into relatively small and simple molecules, soluble in water. These gradually link up further, presumably into chains, forming a syrupy mass

with a lower solubility in water ; and at this stage the whole mass can be incorporated with fillers to form a moulding powder, which on moulding by heat is thermo-hardened into a cross-linked and three-dimensional polymer.

A typical moulding-powder composition would be approximately equal parts of synthetic resin and wood-meal, together with one or two per cent of pigment, plasticiser, mould-lubricant, and so on. A filler such as wood-meal is used not merely to reduce the proportion of relatively expensive synthetic resin in the product but also to produce mechanical strengtn in the moulded product and to increase the ease of moulding. A wide choice of other fillers is available in order to produce special properties, such as high impact resistance, high thermal resistance, or high thermal conductivity, in the final moulded article. The use in this connection of slate and mica dust, asbestos, cotton fibre, and other materials will be dealt with briefly in the second part of this paper. Sometimes, however, a moulding-powder may contain no filler at all, but only synthetic resin and possibly a pigment. For example, Diakon and certain of the newer urea-formaldehyde resins are made up into moulding-powder form without any filler, in order to give the transparent or translucent ornamental mouldings so much in demand nowadays.

Recently there has come into renewed favour an earlier method of forming synthetic resins into manufactured articles, quite distinct from the use of moulding-powders, namely the so-called cast-resin technique. In the reaction between phenol and formaldehyde, or between urea and formaldehyde, it is possible to arrest the combination at a point where the resulting A-stage product is still syrupy and semi-liquid. It may then be poured into moulds and cured to the final C-stage by controlled heating. Although the use of cast resin is at present largely confined to the production of ornamental objects, wide extensions of the technique may be anticipated. The casting method may also be applied to true monomeric liquids such as styrene and methyl methacrylate ; the transparent plastic Perspex is in fact produced in sheet form by polymerising methyl methacrylate in a heated chamber between glass plates. The sheets, if heated, can be further worked into various shapes, and are widely used, for example, for transparent aircraft gun-turrets. A technique intermediate between moulding and casting is now also finding some technical applications. For example, the monomeric and polymeric forms of methyl methacrylate can be mixed together to form a sort of dough, which can then be fully polymerised by gentle heating in very simple and inexpensive moulds ; and this is increasingly used in the manufacture of dentures.

Formation of Plastic Films and Fibres : Plasticisers

Synthetic and other plastics have in general a remarkable power of forming coherent water-proof films and membranes when solutions of them are spread on solid surfaces and the solvent is allowed to evaporate, thermo-hardening coatings being further heat-cured to make them insoluble.[10] This membrane-forming property is made use of, for example, in the enormous annual output of cinema and photographic films, which is nowadays mainly on a base of cellulose acetate strip, and also to an extremely large extent in the paint and lacquer industry, apart altogether from the moulding industry, which might at first sight appear to be almost the sole outlet for plastics. One particular group of synthetic resins, known usually as the alkyds, of which the glyptals are the most important, finds in fact practically no application in moulding, but is the basis of countless water-proofing lacquers, including many of those now used in the motor-car industry. Thermoplastics like cellulose acetate, polystyrene, and the chlorinated rubbers, as well as thermo-hardening resins such as the phenolics, are all used nowadays in paints and lacquers, in addition to the glyptals mentioned above ; and the two latter in particular are sometimes modified by being compounded with linseed oil, which for centuries formed practically the sole basis of oil-paints, or with its more modern challengers, such as tung oil. The interesting thing here is that the drying and film-forming process in linseed oil, known empirically for so long, is now widely believed to be basically similar to the process of thermo-hardening in synthetic resins—that is to say, linseed oil probably hardens by the conversion of unit molecules into cross-linked three-dimensional molecules, accompanied this time by oxidation under the influence of atmospheric oxygen. In other words, the hardening, or " drying," of such oils is classed as still another example of polymerisation. The cross-linking conversion here takes place under the influence of an outside element, oxygen, and not simply by heating ; and the term *element-convertible* is therefore sometimes applied to such polymerisable materials, in contrast to the term *heat-convertible*, which, as already stated, is often used in America instead of *thermo-hardening*.

It may conveniently be noted at this point that many film-forming plastics also form threads and filaments with great ease. Many of these, by suitable methods of extrusion, coagulation, or spinning, may be produced with a remarkably high tensile strength : and one of the two main types of artificial silk or rayon is composed of fibres of cellulose acetate. This is an enormous subject, and cannot receive more than this brief mention in the present paper : but it should be noted, as an indication of the trend of

modern textile research, that many new textile fibres are now being produced from materials falling within the category of plastics and synthetic resins—the Nylons, which are synthetic fibres closely approximating to natural silk ; Vinyon, an almost non-inflammable polyvinyl plastic fibre ; Lanital, a wool-like fibre produced from milk-casein ; and Fibre-glass, a remarkable in-organic fabric woven from very fine glass fibres. Wide developments may be expected in this field.

Another wide subject, namely plasticisers, can only be touched upon briefly here. Many plastics are to some extent brittle in their final form—moulded object, film, or filament—pure polystyrene being a particularly bad offender in this respect. It is found, however, that the brittleness may be substantially reduced and the properties of elasticity and general toughness much enhanced by the incorporation of varying amounts of materials known as plasticisers. Usually, plasticisers are high-boiling liquids, though at least one solid plasticiser is in wide use, namely camphor, which has been used to plasticise nitro-cellulose since the very early days of the industry. Usually, too, the plasticiser forms only a small proportion of the finished plastic ; but there is at least one group of plastics, the polyvinyl chlorides, in which the greater part of the finished product may consist of plasticiser.

Natural Chain-Molecules : Cellulose and Celluloid

Now that some idea has been given of what the synthetic plastic materials are like, and how their molecular structure governs their moulding characteristics, their relation to natural chain-molecular compounds may be briefly indicated. Natural cellulose, silk, and wool, though essentially chain-molecular, are for several reasons not thermoplastic. One reason, which cannot suitably be discussed in detail here, is the existence of a special kind of weak cross-linking (reinforced in wood by occasional normal cross-links), which does not destroy the basic chain-like structure. Another reason lies in the fact that such materials are relatively unstable when heated. Their long chain-molecules are fringed with very sensitive and reactive chemical groupings ; and if we try to render them thermoplastic by heating they split up chemically into simple substances, either by a splitting of the chain into shorter lengths or into its individual component molecules, or even by decomposition of the component molecules themselves. But it is sometimes possible, by replacing the reactive groups along the chain by various more stable groups, to render the chain less heat-sensitive, and to enable temperature at which the material is thermoplastic to be reached without decomposition. This is what is done in the formation of celluloid and gun-cotton, which are

amongst the earliest of the industrial plastics, and of cellulose acetate, from which some artificial silks are made. Here, by the action of nitric acid and acetic anhydride respectively, most of the reactive groups of the cellulose chain have been converted into less reactive groups. The material is now thermoplastic, though care must still be taken not to heat it too strongly during moulding, since this might break down the molecular chains and alter the properties of the material.

Practically all the natural polymers such as cellulose exist as linear chain-molecules, whereas several of the most important synthetic polymers form cross-linked molecules. But at least one important natural plastic, namely shellac, is to some extent thermo-hardening. When first heated, it may be considered as a thermo-plastic, in the sense that the A-stage of Bakelite is thermoplastic ; and it further closely resembles the Bakelite type of resin, in that if it is kept at 100°C. for a long time it becomes progressively less and less soluble, and its indefinite softening-point rises steadily, until eventually it becomes almost completely insoluble and in-fusible. In other words, it becomes thermo-hardened or cured into a cross-linked polymer, presumably because in the original material there are many unattached linking-groups of the same general type as those in A-stage phenolic resins.[11]

It may also be remarked that in natural chain-molecules the component units are not always identical with one another, as in synthetic polystyrene, though they are always closely related chemically. Thus, in wool, the chain-molecule is composed of a more or less random sequence of some seventeen slightly different kinds of unit molecules, though two of these kinds preponderate greatly over all the others. In the field of synthetic thermoplastics, a similar result may be obtained by, for example, co-polymerising a mixture of vinyl chloride and vinyl acetate. When polymerised separately, these give long chain-molecules of polyvinyl chloride and polyvinyl acetate respectively ; but when polymerised together they yield chains composed of both types of unit molecule, linked up at random in proportions depending on their ratio in the original mixture. The polyvinyl plastics known as Mipolam and Vinylite V, for example, are made thus ; and a similar kind of co-polymerisation is used in the manufacture of some grades of so-called synthetic rubber, for example, Buna S, Buna N, and butyl rubber, which are dealt with briefly in the following section.

Rubber, Vulcanisation, and Elasticity

One of the main differences between natural and synthetic chain-molecules is that the former are usually grouped parallel to one another, whereas the latter are in general oriented quite at random, like the fibres in a piece of felt. Further, bundles of

natural polymer-molecules may, in materials such as muscle, be loosely linked together by mutual attraction of the reactive groups fringing adjacent chains : and a great deal of the strength and elasticity of natural fibrous materials is derived from this orientation of chain-molecules into parallel bundles. It is instructive to note that a number of recent patent specifications describe special methods of producing threads and films of plastics such as Nylon and polystyrene with the chain-molecules parallel to one another and much tougher and more resilient than those produced by the ordinary methods of moulding, where the chains are oriented at random.

As has already been pointed out, the natural chains are essentially one-dimensional ; but they nevertheless need not be geometrically linear. Many are folded, or coiled. For example, the chain-molecules of silk are practically fully extended, but those of wool are zig-zag and crumpled, which explains why wool fibres can more readily be stretched than silk. [12] It has also been shown that the chain-molecules of the elastic form of rubber are coiled into cylindrical spirals, a fact which might lead one to predict the characteristic elasticity of rubber by a simple mechanical analogy. Actually, according to recent views formulated by Mayer, the contraction of stretched rubber is due to the fact that in relaxed rubber the chains are folded or coiled in one of many possible geometrical configurations, whereas when the chains are stretched the links become oriented into a much more regular and almost crystalline arrangement—one of only a few possible configurations. In other words, to use a thermo-dynamical term familiar to the engineer, the stretched rubber molecule is a system of low entropy and low thermodynamic probability, and will naturally strive to revert, by contraction, to a relaxed system of high entropy and high thermodynamic probability. [13]

Rubber itself is a huge subject ; but we can here devote only a few moments to it in passing. As the material comes from the rubber tree it is a milky fluid known as rubber latex, in which the suspended globules of rubber appear to consist of aggregates of chain-molecules composed of carbon and hydrogen atoms, each of whose component unit-molecules contains a pair of unattached potential linking-groups. When first separated from the rubber latex, raw rubber is thermoplastic, tacky to handle, soluble in some solvents, and not well suited to most of its modern applications without further treatment, which consists, as is well-known in vulcanisation, in which the rubber is mixed and heated with a material such as sulphur. The reaction is generally though to be parallel to that previously described between styrene and divinyl benzene—in other words, the sulphur atoms possess links that can attach themselves to the free linking-groups of the rubber

chain-molecules, and can therefore act as bridges or cross-links between the chains. Theoretically, a very small amount of sulphur (about 0.02 per cent) would be sufficient to link together all the chains in an aggregate of rubber latex, just as a very small trace of divinyl benzene renders polystyrene less soluble ; but in actual practice about 0.15 per cent is required to begin the vulcanisation. As more and more sulphur bridges are introduced the vulcanised rubber becomes progressively harder and less soluble : and in fact hard ebonite or vulcanite is made by vulcanising rubber with as much as about 30 per cent of sulphur. Of course, even ebonite itself is still somewhat thermoplastic, as may be seen by holding the stem of a pipe in a jet of steam—a fact which has already been commented upon. It has, however, lost nearly all its elasticity, and is now brittle, which may indicate that the adjacent coiled or folded chain-molecules have become too closely interlocked by the sulphur bridges, though they can still be stretched and relaxed in ordinary vulcanised rubber, and the material shows elastic rather than plastic deformation.

It is a curious fact that under the stress of war-conditions synthetic chemistry has nowadays surrounded rubber, which was at one time unique in its elastic properties, with a large group of allied materials displaying the same properties to a greater or less extent. These include straightforward synthetic rubber-substitutes, such as the German Buna rubbers ; the rubber-like oil-resisting substance Neoprene ; and compounds such as the colourless and transparent polyvinyl acetate, whose only obvious relation to rubber is its elasticity under some conditions. All, however, have a very similar molecular skeleton, to which the reversible cycle of extension and contraction can be attributed : and here, once again, we have a section of the plastics field where many seemingly unrelated facts are found to be covered by one simple generalisation.

The whole of the field of rubber-like synthetics is an extremely interesting and complicated one : and there are several excellent publications available [14] for those who wish to follow out in detail the complications of war-time economics, nomenclature, and properties.

Glass and Ceramic Materials

But now, having indicated that the whole subject is extremely simple in outline, it is possible that we may have overshot the mark and over-simplified the picture : and we must in all fairness indicate that there are one or two apparent departures from the strict simplicity which has so far been assumed.

Consider that common material, glass. Here, surely, is the ideal thermoplastic of all the classical definitions. It can be softened

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by heat, and moulded; it hardens again on cooling; and the process can be repeated indefinitely. It might, therefore, be expected that the molecules would consist of long chains; but, although there are still some points to be cleared up on the exact molecular structure of the glasses, most evidence, such as that brought forward in America by Zachariasen, tends to show that there is an irregular three-dimensional skeleton mesh-work composed of oxygen and silicon atoms. Fig. 5 (after Zachariasen) shows the general type, though it is reduced for simplicity to a two-dimensional representation. Each silicon atom throughout the
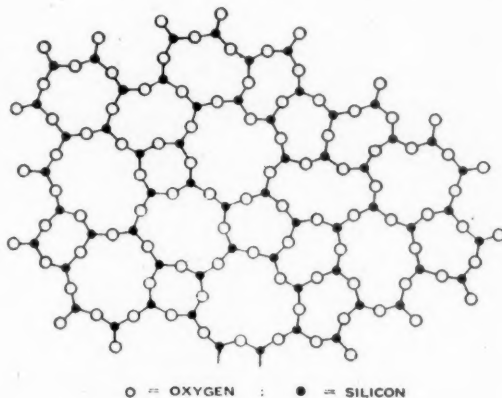
O = OXYGEN : ● = SILICON

FIG. 5. BASIC STRUCTURE OF GLASS.

mesh is attached to, and surrounded by, four oxygen atoms, which occupy the points of a more or less regular tetrahedron about the central silicon (the fourth oxygen atom must be imagined in each case as being above or below the plane of the illustration, thus extending the mesh into three dimensions). The other atoms making up a typical glass—sodium, calcium, lead, and so on— are inserted into the interstices and spaces of this very irregular network, probably rather at random. [15]

Here, then, is an apparently exceptional case—a typical thermo-plastic with an almost certainly three-dimensional mesh. It is difficult to give briefly, in non-chemical language, a rational explanation of this; but it is connected with the fact that glasses are made up of inorganic salts, such as the silicates of sodium, calcium, and lead, which are ionisable, in marked contrast to the

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non-ionising organic molecules of polystyrene, phenolic resins, and so forth.

In ordinary pottery, too, and in such kindred materials as the heat-resisting mouldings based on Portland and other cements, we must apparently depart from the simple theory that covers the organic synthetic resins ; for although plastic clay thermo-hardens irreversibly into a three-dimensional mesh-work of silica and silicates when the water is driven off by firing it does not seem to have a chain-molecular structure in its original plastic state. The plasticity of clay falls into a different category, which is difficult to describe briefly, but is a kind of lubrication effect, the individual mineral particles being kept separate by a surface film of water-molecules. We should, then, qualify our generalisations with a mild warning. Although the conception of chain-molecules and mesh-molecules provides an excellent explanation of the properties of organic plastics in general, which gives the key to many otherwise puzzling phenomena, and is undoubtedly correct in its broad essentials, it is well to apply it with caution to the somewhat exceptional field of inorganic plastics.

PART II

The Uses, Properties, and Methods of Application of Plastics, with Special Reference to Moulding-Technique

By I. W. A. KIRKWOOD, M.I.E.E., M.A.I.E.E.

General

The first part of this paper has described the fundamental chemical reactions underlying the production of moulded articles from the so-called plastic materials, and it is now proposed to examine briefly the commercial applications of these materials in greater detail. For the sake of clarity, the subject is treated under four headings, namely :

Manufacture of mouldings.
Properties of moulded plastics.
Advantages of plastics.
Commercial applications of the principal plastics.

Manufacture of Mouldings

Various substances will be referred to under their technical classifications and the particular uses of the individual materials will be described later, but at this stage it is sufficient merely to remember the broad definitions.

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(a) Thermoplastic materials are appreciably softened by heat after moulding ; they re-harden on cooling ; and the cycle can be repeated any number of times.

(b) Thermo-setting materials are hardened by chemical changes, and do not soften appreciably when re-heated.

Methods of Production

INJECTION MOULDING

Injection moulding is up to the present time applicable only to thermoplastic materials. The material is heated in a cylinder and forced, while still hot, into suitable moulds in something like the
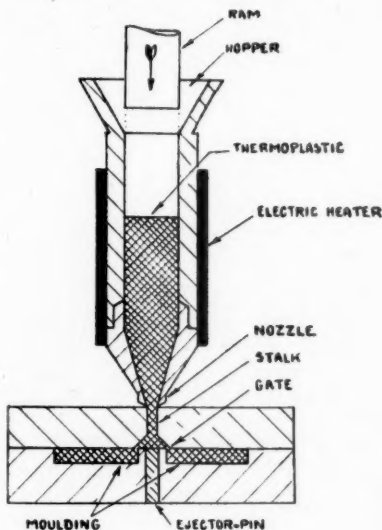
FIG. 6. INJECTION-MOULDING UNIT.

way an ordinary grease-gun is used. Water is circulated round the moulds to cool the articles, which are then ejected ready for use except for minor trimming. Fig. 6 shows the essential features of a typical unit for this purpose, and Fig. 7 illustrates a typical batch from a moulding cycle.

EXTRUSION MOULDING

Extrusion moulding is, basically, a simplified form of injection moulding. The hot material is forced through suitable dies or

nozzles, which produce long continuous strips of uniform section (see Fig. 8).

PRESSURE (OR COMPRESSION) MOULDING

In pressure-moulding, a steel mould is charged with moulding-powder—either as such, or pre-formed by cold compression—
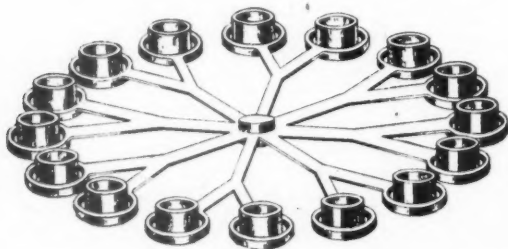
FIG. 7. BATCH FROM AN INJECTION-MOULDING CYCLE

and pressed between platens heated by steam, gas, or electricity, thus forcing the softened plastic into all the corners of the mould. With thermoplastics, the mould must then be cooled to impart rigidity to the finished article before extraction, whereas thermosetting materials may be extracted whenever they are fully cured. Moulding-presses may be either up-stroke or down-stroke (the
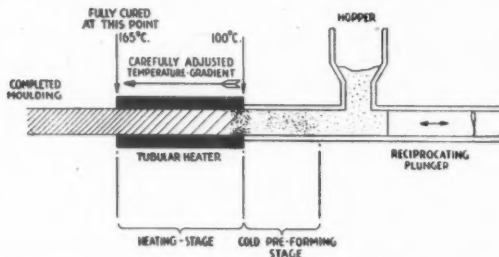
FIG. 8. EXTRUSION-MOULDING OF THERMO-HARDENING PLASTICS.

bottom or the top platen movable, respectively) and also either single-daylight (one space or daylight between top and bottom platens) or multiple-daylight (with the aperture divided by an intermediate heated platen or platens). Fig. 9 shows a 100-ton

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up-stroke press, originally single-daylight, but modified by adding an intermediate platen so that is could be used as a two-daylight press if required. The illustration shows it with the extra platen locked against the top, making it, in effect, single-daylight, since the very long mould requires all the available space. To counter-
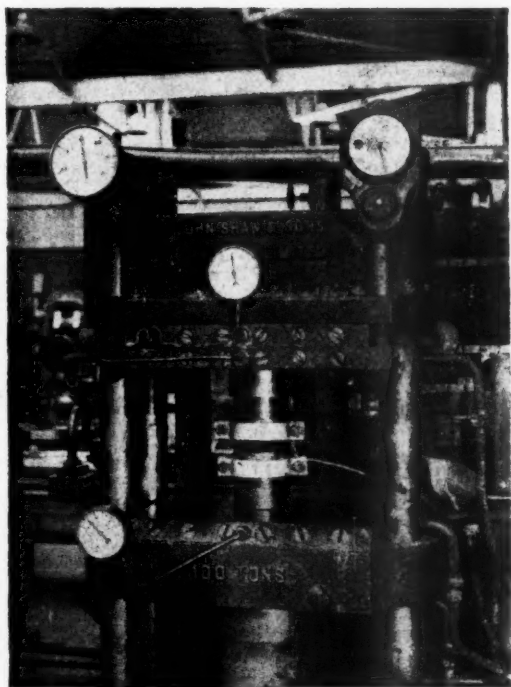
FIG. 9. TYPICAL MOULDING-PRESS.

balance heat-losses from the middle of the long mould, auxiliary heaters have been fitted. Pre-heating the powder by a high-frequency electrostatic field, prior to final curing. is a recent development, which markedly reduces total moulding-time, and also facilitates uniform heating of awkwardly-shaped articles.
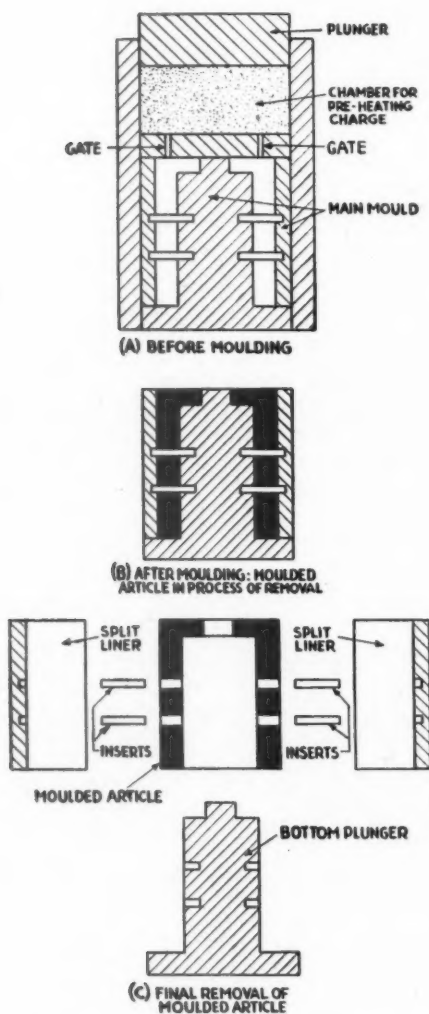
FIG. 10. STAGES OF TRANSFER MOULDING.

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TRANSFER (OR FLOAT) MOULDING.

Transfer moulding has only recently been developed; it is, in effect, a combination of injection moulding and compression moulding applied to either thermoplastic or thermo-setting materials to enable delicate or long unsupported inserts to be incorporated without damage. The basic principle is that the moulding-material is pre-heated in the top chamber, and when sufficiently fluid enters the main mould through holes appropriately positioned in the intermediate plunger (see Fig. 10). This ensures that the moulding-material is fluid when it surrounds the insert, and the pressure acts as a uniform fluid pressure, which does not tend to distort the insert.

CASTING

Casting liquid resins, in much the same way as casting metals, is another process now coming into use. The setting of cast metals is purely a thermal process, but the setting of cast plastics is usually due to chemical reaction. The shrinkage is usually very great, sometimes as much as 14 per cent ; and precautions must therefore be taken to prevent the formation of voids. Only comparatively light pressures are necessary, and hence quite inexpensive metal moulds, or sometimes even plaster-of-paris moulds, are all that are required.

STAMPING

From some plastic materials in sheets stampings or pressings can be produced in much the same way as from metal.

Moulds

The types of moulds generally used are illustrated in Fig. 11 ; but these do not include moulds for casting, which have already been sufficiently dealt with.

FLASH MOULDS

Flash moulds are so called because any excess of powder, known as a flash, is allowed to escape round the sides of the mould ; this avoids having to weigh the charge of moulding-powder accurately.

SEMI-POSITIVE MOULDS

Semi-positive moulds allow only a limited amount of excess to escape. Their advantage over flash moulds is that they facilitate to some extent the charging of multiple moulds and the extraction of finished articles from them.

POSITIVE MOULDS

Positive moulds give a positive pressure on the moulding. With them, more accurate weighing of the charge is necessary, but on the other hand better and more homogeneous articles are produced

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than with flash moulds, in which lack of pressure tends to give a poor finish, particularly at the edges. Pre-forming of the moulding charge is sometimes used to speed up production with positive moulds.

BLOW MOULDS

Blow moulds are for producing hollow articles. The necessary materials is placed in the mould in the form of a thermoplastic tube ;
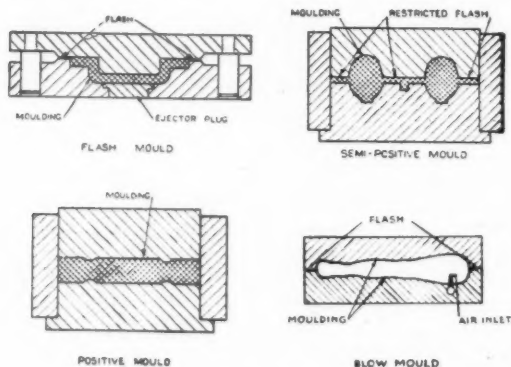
FIG. 11.   IMPORTANT TYPES OF MOULDS.

the mould is then heated, and air is injected into the tube in order to press it against the sides of the mould. The mould is water-cooled before the finished moulding is extracted.

TEMPORARY MOULDS

One of the difficulties that until recently prevented the development of many mouldings was the necessity of providing expensive moulds before articles could be produced ; it is frequently only after extensive tests that it is found that some modification would have been desirable ; but this cannot be made once a permanent mould has been manufactured. A recently developed technique permits the production of a small number of articles from in-expensive temporary moulds made from easily-machined cast-zinc alloys. An advantage of this is that samples can be moulded for test, and the moulds can be melted down and remade if they are unsatisfactory or when they are finished with. In the manu-facture of electrical mouldings by this method care must be taken that none of the mould is transferred to the surface of the moulding,

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since this may lead to low insulation-resistance. Later practice has included promising experiments with moulds of high-grade cast iron instead of zinc.

X-Ray Examination of Finished Mouldings

Something may be said about the X-ray examination of finished mouldings, which has been found to be of great assistance in detecting, without damaging a moulding in any way, what have hitherto been hidden faults only to be discovered by expensive test-methods usually involving the destruction of the moulding, whether faulty or not. Some manufacturers now use it in addition to their other various quality-tests in order to check periodically the quality of their products. Usually the first few batches from any mould are examined, and later check-tests are made from
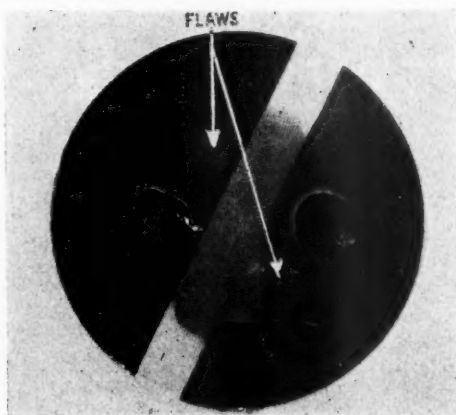
FIG. 12.   X-RAY PHOTOGRAPH OF MOULDING WITH
INTERNAL FLAWS.

time to time. Figs. 12 and 13 show X-ray photographs of mouldings with internal flaws that would have been very hard to detect without destroying the mouldings, and it might even have been necessary to destroy a large number before faults of this kind could have been discovered. Fig. 14 shows a section of the moulding illustrated in Fig. 12, in which the flaws are clearly discernable.

A point to be noted in connection with styrene is that a number of investigators have reported a considerable drop in its insulation-resistance when subjected to X-ray examination, and that this has persisted for a considerable time after the removal of the X-rays.

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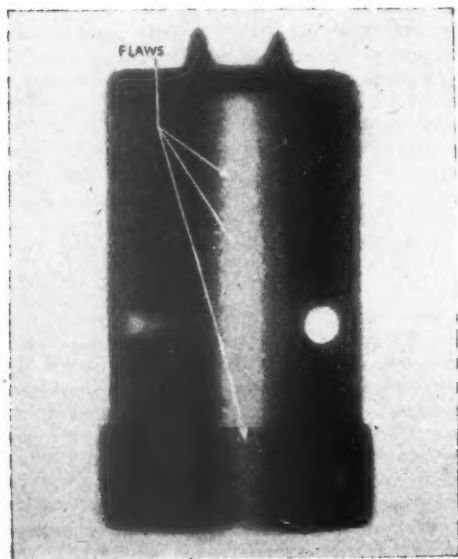
FIG. 13. X-RAY PHOTOGRAPH OF MOULDING WITH
INTERNAL FLAWS.
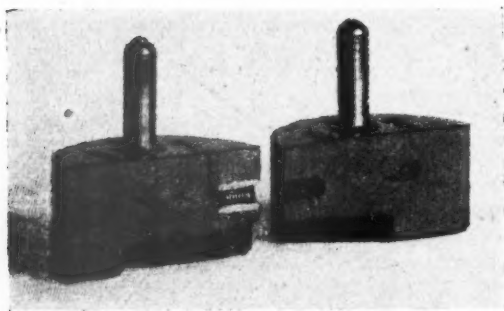
FIG. 14. SECTION OF MOULDING SHOWN IN FIG. 12.

It has also been observed by the author during the examination of other materials such as ebonite, polymethyl methacrylate, and laminated phenol formaldehyde bonded materials, but in these the resistance of the surface only drops during the application of the X-rays, and immediately recovers after switching off.

Properties of Moulded Plastics

The fundamental chemical classification adopted in the first part of this paper was to group the materials under the two headings of :

(a) chain-molecules and

(b) cross-linked molecules ;

but from the user's standpoint this is hardly satisfactory because for him the way in which an article produced is of secondary importance to whether or not it behaves satisfactorily in service. Any universal classification is impossible owing to the diverse uses of plastics ; for example, they are extensively used not only in the electrical but also in the building and other industries.   It has therefore been found most convenient to standardise only the test-methods to be adopted for determining their properties, and for users to specify their requirements accordingly.   One of the main general limitations of plastics is the temperature at which they operate satisfactorily.   This is particularly so in the electrical industry, and for this reason maximum operating temperature is one of the best bases on which to classify plastics.

In view of the wide choice of available materials, the closest possible cooperation between manufacturer and user is essential if the maximum benefit is to be obtained from a proper use of the materials.   Each has his own definite responsibility, for example :

(a) The user (or the purchaser) must specify clearly and concisely the properties he requires, or, alternatively, the exact conditions of service. For example, it is not sufficient simply to specify a Bakelite moulding, because there are so many different grades, each designed for some specific purpose, practically the only common features being some of the basic chemicals themselves.

(b) The manufacturer must use the most suitable materials available to produce the required results having due regard to available facilities, and must ensure by periodic tests that the necessary quality is consistently maintained.

The following properties, with their various sub-divisions, are those usually looked upon as the main characteristics of a material,

although special circumstances may of course accentuate the necessity of some other quality :

(a) electrical properties (electrical strength, power-factor, and specific inductive capacity) ;

(b) mechanical properties (tensile, compressive, cross-breaking, and impact strengths) ; and

(c) physical properties (specific gravity, moisture-absorption, and inflammability).

The effect of temperature on these properties is also an important characteristic.

It is not possible to deal fully with each individual property, but an attempt will be made to indicate briefly the general characteristics of the most important materials.
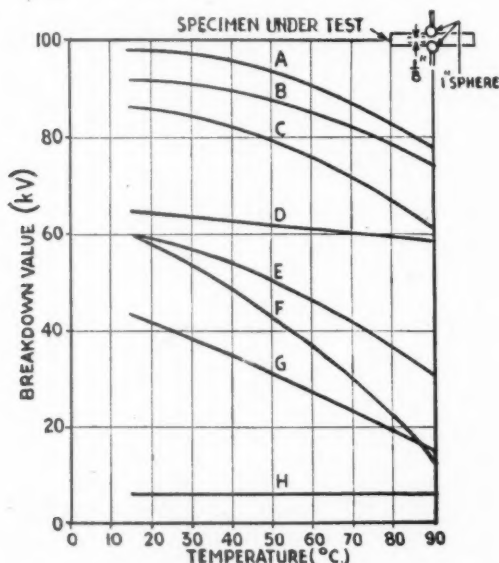
A.—Polymethyl methacrylate.
B.—Cellulose acetate.
C.—Rubber (hard).
D.—Phenol formaldehyde, mica-filled.
E.—Phenol formaldehyde, high - quality - cellulose - filled.

F.—Urea formaldehyde, cellulose-filled.

G.—Phenol formaldehyde, flaked-cloth-filled.

H.—Cement, asbestos-filled.

FIG. 15.   ELECTRIC-STRENGTH/TEMPERATURE CURVES.

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Electrical Properties

Fig. 15 shows the effect of temperatures on the electric strength of some of the more commonly-used plastic materials, and a more detailed list is given in Appendix C. The main point is that rise of temperature usually produces a drop in electric strength;
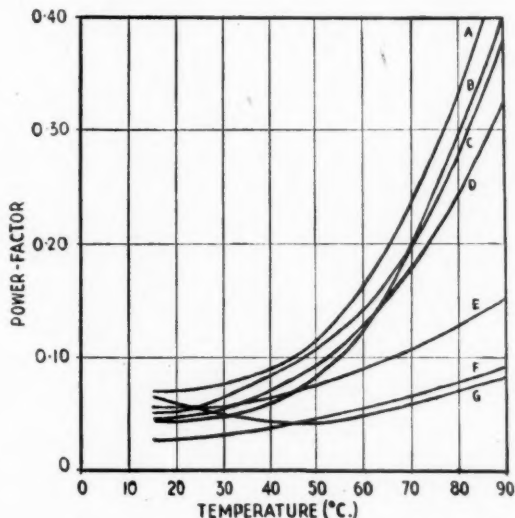
A.—Polymethyl methacrylate.
B.—Urea formaldehyde, cellulose-filled.
C.—Phenol formaldehyde, high - quality - cellulose - filled.
D.—Cast resin (phenolic).
E.—Rubber (hard).
F.—Phenol formaldehyde, mica-filled.
G.—Cellulose acetate.

FIG. 16. POWER FACTOR/TEMPERATURE CURVES.

for example, serious drops, as much as 50 per cent between 15°C. and 90°C., occur in wood-filled and paper-filled phenol formaldehyde and urea materials. Apart from the cement-asbestos type, which has negligible insulating properties, mica-filled phenol formaldehyde material appears to be least affected.

Fig. 16 similarly shows the effect of temperature-rise on power-factor ; and here again the effect is, in general, to cause a deterioration in the power-factor characteristics.

Mechanical Properties

The range of mechanical properties available is largely controlled by the type of filling material used in the moulding, and by the method of incorporating it.

The following table shows how the properties of a plastic (actually a phenol-formaldehyde moulding) can be varied by the adoption of different fillers.

FILLER	CHIEF PROPERTY IMPARTED TO MOULDING
Common wood flour	General all-round properties
Specially-selected wood flour	Electric strength
Paper	Electric strength and decreased tendency to track
Mica	Lower power factor and decreased tendency to track
Asbestos	Heat-resistance
Glass fibre	Low power-factor, mechanical strength, and decreased tendency to track
Silica	Thermal conductivity
Graphite	Self-lubrication
Cloth fibre, flaked cloth, or cloth laminations	Mechanical strength, particularly shock-resistance
Uranium salts	Luminosity

Superior mechanical properties, if essential, particularly high shock-resistance, are obtained by the addition of fibrous materials such as asbestos and cotton, either felted or woven into cloth or cord, or as individual fibres, although unfortunately this usually results in the deterioration of other qualities, such as the electrical properties. The reason for the increase of mechanical strength is shown by Fig. 17, which compares phenol formaldehyde mouldings, (a) with mica filling, (b) with flaked cloth filling, and (c) with cloth laminations.

The great importance of the effect of temperature-rise on mechanical stability is shown by Fig. 18. As would be expected, the thermoplastic materials are the most seriously affected, but
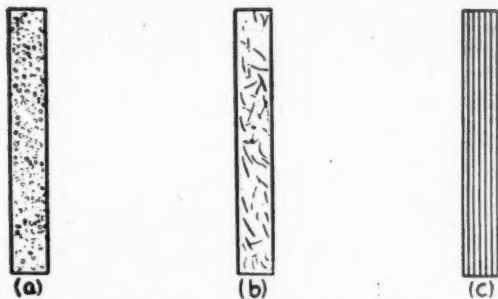
(a) **MICA FILLING**: Strength depends on adhesion between particles:
    Tensile strength 5,000 lb./sq. in.
    Compressive strength 16,500 lb./sq. in.
    Impact strength (Izod) 0.1 ft.-lb.

(b) **FLAKED CLOTH**: Structure is partially reinforced by fibres in **all** directions:
    Tensile strength 6,500 lb./sq. in.
    Compressive strength 34,000 lb./sq. in.
    Impact strength (Izod) 1.5 ft.-lb.

(c) **CLOTH LAMINATIONS**: Structure is completely reinforced longitudinally by strips of cloth:
    Tensile strength 17,000 lb./sq. in.
    Compressive strength (edgewise) 25,000 lb./sq. in.
    Impact strength (flatwise) (Izod) 6.0 ft.-lb.

FIG. 17. EFFECT OF FILLERS.
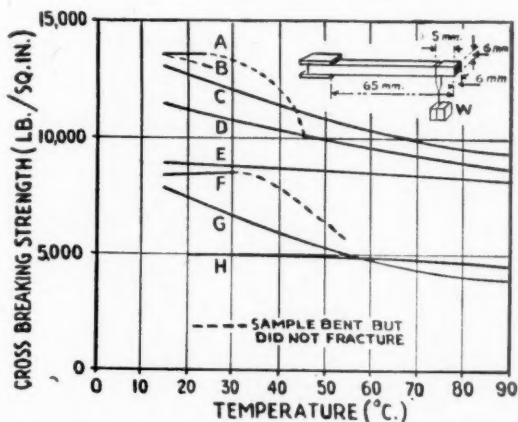
A.—Polymethyl methacrylate.
B.—Cellulose acetate.
C.—Phenol formaldehyde, flaked-cloth-filled.
D.—Phenol formaldehyde, high-quality-cellulose-filled.
E.—Cement, asbestos-filled.
F.—Rubber (hard).
G.—Urea formaldehyde, cellulose-filled.
H.—Phenol formaldehyde, mica-filled.

FIG. 18. CROSS-BREAKING-STRENGTH/TEMPERATURE CURVES.

cellulose (wood or paper) filled phenol and urea mouldings also show serious depreciation.

Appendix C gives the mechanical characteristics of the most usual types of plastics.

Physical Properties

SPECIFIC GRAVITY

At first sight it might appear that specific gravity is unimportant, but for such purposes as aeroplane-manufacture any saving of weight within the permissible limits of mechanical strength is of value ; and the low specific gravity of many plastics as compared with that of the commoner metals makes them particularly useful in this connection by offsetting their lower mechanical strength. The two tables below illustrate this by showing approximate relative weights of a number of materials when used as struts of a given length to support a given load (a) in compression and (b) in

MATERIAL		APPROXIMATE RELATIVE WEIGHT IN COMPRESSION
METALS	Cast brass	0.7
	High-tensile steel	0.9
	Duralumin	1.0
	Cast iron	1.0
WOODS	Spruce	1.0
	Ash	1.1
	Pine	1.6
PLASTICS	Phenol formaldehyde, high-quality-cellulose-filled... ...	0.5
	Phenol - formaldehyde - bonded cloth laminations (laminae flatwise)	0.5
	Urea formaldehyde, cellulose-filled	0.5
	Phenol formaldehyde, flaked-cloth-filled	0.5
	Cellulose acetate	0.8
	Phenol - formaldehyde - bonded cloth laminations (laminae edgewise)	0.8
	Cast resin (phenolic)	1.0
	Polymethyl methacrylate ...	1.2
	Phenol formaldehyde, mica-filled	1.3
	Rubber (hard)	2.0
	Bitumen, mineral - and - fibre - filled	3.0

tension. The values indicate that in the present state of the art plastics in compression are on the whole better than the competitive other materials, although they are not as good in tension.

	MATERIAL	APPROXIMATE RELATIVE WEIGHT IN TENSION
METALS	Duralumin	1.0
	High-tensile steel	1.2
	Cast brass	2.7
WOODS	Spruce	0.8
	Ash	1.3
	Pine	1.8
PLASTICS	Phenol - formaldehyde - bonded cloth laminations	2.1
	Cast resin (phenolic)	3.1
	Urea formaldehyde, cellulose-filled	3.3
	Phenol formaldehyde, flaked cloth-filled	3.9
	Phenol formaldehyde, high-quality-cellulose-filled. ...	4.1
	Rubber (hard)	4.5
	Cellulose acetate	4.6
	Polymethyl methacrylate ...	4.7
	Phenol formaldehyde, mica-filled	8.2
	Bitumen, mineral - and - fibre filled	12.3

Recent developments in connection with corded and sheet materials have tended to produce greater tensile strength, but precise comparative test-data are not yet available for publication.

MOISTURE-ABSORPTION

Resistance to moisture is naturally an important consideration, particularly if the article is intended for outdoor use of for electrical purposes. Appendix C gives detailed information on this point for the most commonly used plastics.

The effect of moisture-absorption is usually to produce swelling and ultimate deterioration, and in addition, from the electrical standpoint, a reduction of electric strength and an increase in power-factor.

In discussing the effect of moisture on various materials attention

must be drawn to the difference between penetration of moisture through a material and absorption of water into it. The former implies that the moisture passes right through the material, leaving it relatively unaffected ; but the latter implies its retention in the material, usually accompanied by deterioration. This is particularly important when plastics are used in thin films as in the varnish industry.

INFLAMMABILITY

Even though plastics do not ignite readily, the majority of them except of course the asbestos, cement, and vitreous materials, can be made to burn. In the present state of the art there is so wide a range of material to choose from that it would appear never to be essential to use highly inflammable material, such as nitrocellulose.

Advantages of Plastics

When considering the economics of plastics it is usually essential to think of production in terms of at least thousands, although for large articles the minimum quantites may be only hundreds. The reason is obvious when one realises that a good mould may quite easily cost as much as £100, even though the price of an article produced from it is only a few pence. Unless, therefore, a large output is achieved, the proportion of the mould charge to be borne by each article makes the cost of this kind of production prohibitive.

It is poor economy to cheapen the mould at the expense of quality. Improperly manufactured moulds wear quickly, and, further, if badly designed may result not only in faulty articles but also in delay in extracting the finished mouldings. Any delay of this kind can be very expensive, since it may represent cumulatively a serious capital charge because of its rendering not only the moulds themselves but the whole of the plant involved nonproductive during its continuance.

On the assumption of properly designed and manufactured moulds, the following are amongst the main advantages of plastics :

(a) A large choice of properties is available, ranging from the resistance to acids and alkalis required by the chemical industry to the high-electric-strength and low-power-factor materials used in the electrical industry, and, alternatively, to the high-mechanical-strength materials used in the construction of aircraft and the like. For the building and domestic trades a pleasing range of colours is available.

(b) Large quantities of identical articles can be produced in a short time with great accuracy, particularly if multiple moulds are used, that is to say those in which a number of similar impressions are sunk, with the result that in one

operation the press produces not one article but a number
depending on the number of impressions. Multiple-day-
light presses are also helpful in speeding up production. For
example, the familiar moulded cups on sale before the war
at most stores and frequently given away for advertising
purposes are usually moulded in batches of six, and the
moulding time rarely exceeds 1 to $1\frac{1}{2}$ minutes per batch.
For injection mouldings, particularly articles like caps of
tooth-paste tubes, semi-automatic machines are available,
capable of turning out as many as 28,000 in an average
8-hour working day.

(c) When compared with older methods of producing articles,
moulding represents a great saving in cost of raw material,
since it only requires enough for the article itself plus
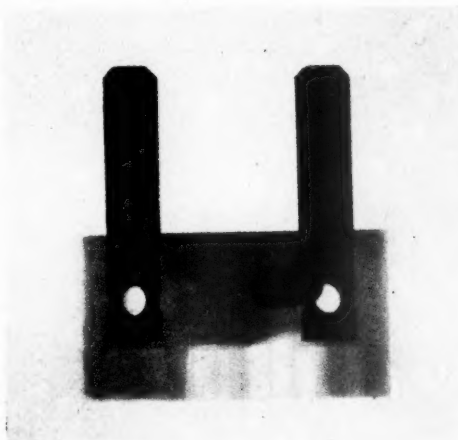
FIG. 19. X-RAY PHOTOGRAPH OF MOULDING WITH METAL INSERTS.

perhaps a very small quantity wasted in the flash, and even
this can be recovered when the material is thermoplastic.

(d) The finish is an integral part of the article and does not tend
to flake off or rust like a paint finish on metal articles.

(e) There is no risk of corrosion by electrolytic action such as
may occur with some combinations of metals used in damp
situations.

(f) In the majority of processes the articles as they come from
the mould need only minor treatment to make them suitable

for use, and no subsequent drilling, tapping, or other machining operation is necessary as it is with most metal articles. In fact, the moulding-press can be considered as a means of shaping plastic materials comparable with a machine tool or tools for the shaping and finishing of metal articles ; and it works much quicker.

(g) The standard of skill on the part of the operator necessary to produce sound and accurate mouldings is lower than that required for the corresponding metal article.

(h) Metal inserts can readily be incorporated, and Fig. 19 shows an ordinary 15-ampere electrical plug moulding in which this has been done. The photograph was taken by means of X-rays, and clearly demonstrates the complete homogeneity of the material and the accuracy with which the brass contact pins have been located.

Commercial Applications of the Principal Plastics

It is quite impossible here to give any comprehensive survey of the multitudinous uses to which plastic materials have been put ; they are extending every day ; and there can be little doubt that when details of our war-effort can be published it will be found that plastics generally have played a remarkably important part. Some idea of the possibilities may be obtained when it is recalled that they are providing very satisfactory substitutes for metals in the manufacture of many articles, particularly in connection with the growing demands of our aircraft industry, where their great strength, the ease with which complicated shapes can be produced, and their comparative lightness, make them absolutely indispensable.

All that it can be hoped to do is to indicate perhaps some of the most interesting and less well-known uses, but before doing so it may be well to indicate the extent to which the plastics industry is even now growing.

A recent government report showed that in 1933 only 12,000 tons of synthetic-resin, casein, and acetate moulding materials were used in Great Britain, whereas by 1935 this had arisen to 24,000 tons, an increase of 100 per cent in two years ; for obvious reasons the figures of present-day consumption are not available. It is interesting to record that even up to immediately before the war the amount of plastics used per head of population in Great Britain was much below that of such countries as America and Germany.

Reference will be made to the ethenoid group of resins, its principal members being polyethylene, polymethyl methacrylate, polystyrene, and polyvinyl acetate and chloride. The group

is of comparatively recent commercial application, but includes a number of the most interesting and useful plastics at present available. Unfortunately wartime limitations have tended to prevent their general development, but because of their special properties have nevertheless helped to speed up their commercial production for specialised purposes. When normal conditions return and the necessity for diverting these materials to other uses ceases, there is little doubt that a number of extremely valuable and interesting developments will become possible.

A number of plastic materials will now be referred to individually.*

ANILINE FORMALDEHYDE

Electrical properties ... ... Good
Mechanical properties	Excellent, but deteriorate with rise of temperature
Usual filler ... ... Paper

Aniline formaldehyde is available commercially either as a solid resin, or, more usually, as a binding resin for paper-filled mouldings It is thermoplastic, but is not appreciably affected by temperatures up to about 100°C. It is claimed that it is less affected by small surface electrical discharges than the corresponding phenolic material.

BITUMINOUS

Electrical properties ... ... Excellent
Mechanical properties	Fair, but deteriorating rapidly with rise of temperature
Usual filler ... ... Silica and asbestos

Bituminous mouldings are mainly used where no appreciable temperature rise is to be expected ; their principal application is where good resistance to acids and the like is required, for example in commercial accumulator cases.

A rather special application of bituminous plastics is in the filling of metalclad switchgear and the like with compound. Here the bitumen is used on account of its good electrical and physical properties, and since mechanical rigidity is of secondary importance it can be used without fillers and a considerably higher temperatures than for normal bituminous mouldings. The metal container may be considered as the mould into which the thermoplastic material is poured ; and it is important to ensure that this is done at the correct temperature. Too low a temperature prevents proper filling, because the compound is too thick, and trapped air-pockets and imperfect adhesion probably result, whereas too high

* Appendix B contains a fuller list of the main industrially-useful plastics.

a temperature may char the compound and damage the other insulation with which it comes in contact. The provision of adequate and suitably-designed expansion spaces in compound-filled enclosures is important ; 6 to 8 per cent of the total volume is usually sufficient under normal conditions.

CASEIN

Electrical properties ... ... Fair
Mechanical properties Moderate, but somewhat unstable
Usual filler ... ... None

The casein materials are produced by curdling and processing milk. They are used chiefly in what may be described as the decorative or domestic trade, in which they have given very satisfactory service. They are extremely easy to machine, and therefore lend themselves readily to mass-production when this is necessary, but unfortunately they have poor weathering properties, and are therefore not of very great value for continuous exposure out-of-doors ; nor are they sufficiently stable for general use in the electrical industry.

CELLULOSE ACETATE

Electrical properties ... ... Excellent
Mechanical properties Good, but considerably effected by temperature
Usual filler ... ... None

Cellulose acetate is amongst the most important of the plastic materials, although the comparatively new groups of ethenoid resins referred to above will probably supplant it in many applications. It is probably best known in the form of non-inflammable film, and as such it is used extensively in practically all industries. Unfortunately, it is a thermoplastic material with a fairly low softening-point (about 45°C. to 60°C.), and therefore, since its mechanical rigidity cannot be relied upon for many purposes, its application is limited.

Besides being readily mouldable, cellulose acetate forms the basis of many adhesives. Some kinds of non-splinterable glass are manufactured by cementing a sheet of it between two glass plates. If the glass is fractured, the splinters adhere to the tough intermediate film, and do not fly as in ordinary glass. Another kind of safety window is manufactured by incorporating a fine metal mesh in sheets of cellulose acetate, the resulting product having excellent shockproof qualities.

Owing to its being thermoplastic, cellulose acetate is particularly suitable for injection moulding, with its associated advantages of rapid production. This, together with the attractive shades of colour available, makes it very popular for numerous domestic

articles, and hair-brushes, spectacle-frames, curtains, and even furniture have all been made from it. Because of its temperature-limitations, however, it is not used very extensively in the electrical industry; but it would be of value where a transparent cover, say for a relay, was required. Unfortunately, however, it tends to become brittle with age.

CEMENT

Electrical properties	Negligible
Mechanical properties ...	Good; good arc-resistance
Usual filler	Silica sand

The cement group includes mouldings both of sodium silicate and calcium-aluminium silicate (Portland cement). The latter is most commonly used with an appropriate filler, often with steel reinforcements when good mechanical properties are required, as in posts, pipes, and the like, and in the building industry, where it is used in temporary buildings by being sprayed on pre-formed frameworks.

Cement mouldings can be impregnated with materials such as bitumen or urea to improve their moisture-resistance and their electrical properties. They are used in the electrical industry as arc-barriers owing to their being relatively unaffected by the momentary application of an arc to their surface. Sodium-silicate-bonded materials are frequently used for this purpose.

MELAMINE FORMALDEHYDE

Electrical properties	Excellent
Mechanical properties	Good; mainly governed by the filler
Usual filler ... Various, mainly cellulose, mica, or asbestos

The melamine formaldehyde resins, which are only of recent development, are extremely water-resisting and very stable. They are produced with a variety of fillers, and, although not yet generally available in Great Britain, they will undoubtedly be valuable in the electrical industry because with a mica filler they do not decompose with the production of carbon when subjected to an electrical arc (that is to say, they are what is known as track-resisting).

They have also been found exceedingly useful in improving the resistance to water of paper materials.

PHENOLIC MOULDING COMPOSITIONS

Electrical properties	Excellent
Mechanical properties	Excellent
Usual filler ... ... Various, but usually wood flour

The most usual members of this group are the phenol formaldehyde compositions and the closely-associated cresol formaldehyde

compositions, which include some of the most important materials at present available, particularly in the electrical industry. Excluding the cast phenolic resins referred to later, they are used rarely, if ever, by themselves, but rather in conjunction with various filling-materials such as wood flour or cotton fibres, which largely control the properties of the finished article. Phenol formaldehyde mouldings, except cast resins, are usually opaque.

Mica-filled phenol formaldehyde powders are used for the manufacture of high-voltage electrical insulators not subjected to great mechanical stress ; but where good mechanical strength is required, combined with high electrical properties, a specially-treated wood filler is frequently used, and 33-kV busbar-support insulators for metalclad switchgear may be so produced.

Much attention has recently been given to the production of mouldings of great mechanical strength. These usually take the form of impregnated fibres, or even impregnated cloths, which are formed into the desired shape by means of heat and pressure. Electrically these materials are poor, but from the weight strength aspect are comparable with aluminium, and are used extensively in the aircraft industry for such parts as control-handles. They also possess the valuable property of being able to work in water without lubrication, and for this reason are becoming increasingly popular for ship-propeller thrust-bearings, as well as for various rollers and bearings in the paper and textile industries. If desired, they may incorporate a graphitic filler to decrease their coefficient of friction.

Another application of fabric-filled phenol formaldehyde materials is their use as mallet heads, since they are safe in places where the usual metallic articles would be dangerous on account of the sparks that might be produced with them.

Another type of phenolic resin is cast resin. Although this has been used in the electrical industry, its main applications have been decorative. As previously stated, it can be produced in a number of attractive shades, ranging from water white to strong colours, and such articles as buttons, buckles, and even artificial jewels, are made from it. It has excellent machining properties, and can also be shaped by heating in hot water or glycerine and bending to the desired shape. Some kinds of cast phenolics also form the basis of acid-resisting plastics used in the chemical and other industries.

Another phenolic composition frequently used is phenol furfural which is derived from grain husks and other farm by-products, and is therefore of particular interest at present. Its characteristics are very similar to those of phenol formaldehyde powders previously

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referred to, with the exception that the resin is rather slower in reaching its final hardness during moulding than the competitive phenolics, and this tends to slow down output.

POLYETHYLENE

Electrical properties	...	...	...	...	Excellent
Mechanical properties	...	...	...	Tough and flexible	
Usual filler ...	...	...	...	...	... ... None

Polyethylene is marketed in Great Britain under the registered trade-name Alkathene. It is a tough and flexible thermoplastic material, but unlike most of the thermoplastics it has a sharp melting-point at about 110°C. Its electrical properties are excellent, and, mixed with polyisobutylene, it is used extensively for the production of cables in the insulation of which low losses are desired, for example those for radio, television, and other high-frequency work.

POLYMETHYL METHACRYLATE

Electrical properties	...	...	...	...	Excellent
Mechanical properties		Good, but affected by temperature			
Usual filler ...	...	...	...	...	... ... None

Polymethyl methacrylate is perhaps better known under the registered trade names of Diakon and Perspex. It is a clear, absolutely colourless material, and is extensively used for aeroplane windows and the like, both on account of the readiness with which intricate shapes can be formed and also because it does not become brittle at low temperatures, such as are encountered in high-altitude flying. It is used too in the manufacture of magnifying-glasses, photographic lenses, and prisms, and in this connection it is claimed for it that it transmits more ultra-violet rays than glass. Further, such optical articles can be produced straight from the mould, and do not require the expensive polishing essential for glass. Mechanically, however, its surface is less scratch-resistant than that of glass, and this has to some extent limited its applications.

It has good electrical properties, and its use in the electrical industry is gradually extending, although difficulty of supplies and price are at present tending to hinder its development. Its property of total reflection from its surfaces, and so of transmitting light longitudinally without appreciable loss, even through a curved tube, is made use of in a number of instruments.

Another of its applications is to the manufacture of dental plates, and here again the ease with which it can be worked is of extreme value. Contact-lenses as a substitute for spectacles are in addition being manufactured from it, and can be accurately formed from castings as individual fits for the eyes under treatment.

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In some special pathological work it is often desired to trace and obtain a record of the path of veins and the like. This is done by mixing an accelerator with the resin, which is then injected into the veins, where it sets rapidly under the influence of the accelerator. The specimen can then be dissolved away, leaving a perfect record in resin of the various veins under investigation.

POLYSTYRENE

Electrical properties	... ...	Excellent
Mechanical properties	Good, but appreciably affected by temperature	
Usual filler ...	Usually none, but sometimes paper	

Polystyrene is used to some extent for injection moulding, but it has found favour in Great Britain mainly as an impregnant for fibrous materials. It is colourless and glass-like at ordinary temperatures, and is particularly valuable in the electrical industry on account of its high moisture-resistance and oil-resistance and its good electrical properties.

POLYVINYL ACETATE

Electrical properties	... ...	Excellent
Mechanical properties	... ...	Excellent adhesive
Usual filler	None ; frequently used as a co-polymer with vinyl chloride	

Polyvinyl acetate is not used extensively in the moulding industry, owing to its excellent adhesive properties, which make it difficult to mould ; but it forms the basis of a number of excellent adhesives. It is of low softening-point, and articles made of it alone tend to flow cold, i.e., to deform at ordinary atmospheric temperatures under their own weight. It is most frequently used in the moulding industry in conjuction with vinyl chloride, and the co-polymer of the two substances has valuable characteristics, which are dealt with in the next paragraph.

POLYVINYL CHLORIDE

Electrical properties	... ...	Excellent
Mechanical properties.	... ...	Tough and flexible
Usual filler		... None

Polyvinyl chloride, which is marketed under the trace-names of Welvec and Vinylite Q, is a tough, flexible, moisture-resisting material with excellent electrical properties, although not quite so good as other members of the ethenoid group, such as polyethylene, so far as dielectric losses at high frequency are concerned. It has been successfully used as a substitute for metal cold-water pipes, and has proved very effective for this purposed. It is also frequently used as a coating on cloth, giving an artificial finish in various

shades, closely resembling leather. The same process is applied to produce first-class graining effects on plywood backing.

Both by itself and as a co-polymer with vinyl acetate, the material is used for the impregnation of fabric in the manufacture of electrical insulating tapes, waterproof articles such as mackintoshes, umbrellas and so on. The co-polymer just referred to, in which the vinyl acetate gives improved resilience and workability, is gradually finding new and interesting commercial applications. Not only are articles like flashlamp lenses so produced, but a number of domestic articles, such as bathroom tiles, hair-brush backs, and the like, are also being made in attractive shades. The manufacturers claim that gramophone records of this material are relatively unbreakable. It can also be used for the manufacture of dentures.

In the electrical industry, similar co-polymers are frequently used in the form of flexible extruded tubing, and are rapidly finding favour in view of the fact that they do not deteriorate with the formation of deleterious acids under tropical conditions, as may happen with some kinds of varnished sleeving. Unfortunately, however, their maximum operating-temperature is 60°C. to 80°C., depending on the grade used, and this characteristic must be guarded against. As an offset, they remain flexible even at temperatures as low as —40°C.

Amongst the more unusual uses of the co-polymers is in substitution for starch in fabrics. This, besides increasing the resistance of the material to dirt and creasing, has the valuable result that articles once treated can be washed in the usual way, and then ironed, and still come out as stiff as before without any additional treatment such as the re-starching required when ordinary starch is used.

RUBBER

Electrical properties	Excellent
Mechanical properties	Flexible ; mainly governed by the filler
Usual filler	For non-electrical purposes, carbon black ; for electrical purposes, metallic oxide

Fortunately the use of rubber is far too well-known to need detailed discussion here ; it could well have a complete paper to itself. Its normal applications in motor-tyres, hot-water bottles, and so on, are also too well-known to need enumeration.

In the chemical industry, rubber is extremely valuable on account of its resistance to most acids and alkalis, and it is extensively used for pipes, cocks, and vats.

In the electrical industry, rubber is very widely used for the insulation of small wiring and trailing-cables, in which its excellent electrical and mechanical properties and moisture-resisting charac-

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teristics are of extreme value. It is also used in the form of hard rubber for the manufacture of high-grade electrical mouldings, in some of which it has been found possible to incorporate electrical-stress-grading condenser-foils. Another use in the electrical and other industries is in the making of watertight and oiltight jointing-materials.

One curious feature of ebonite, which has from time to time given trouble in the electrical industry, is that this hard rubber is compounded with an excess of sulphur, which under the action of ultra-violet light combines with atmospheric ozone to form a conducting skin on the surface, particularly in the presence of moisture. This can be prevented by treating the surface with a suitable finish, such as a cellulose varnish.

Rubber can also be used in mat-surfaced sheets as curtain-material, which needs only sponging to keep it clean ; and it has also been tried for horseshoes to minimise noise.

SHELLAC

Electrical properties	...	...	...	...	... Good
Mechanical properties	...		Fair, but readily affected by temperature
Usual filler ...	...	...	...	...	Mineral and fibre

The use of shellac has been gradually diminishing, owing to the development of the newer thermo-setting resins. Although several very promising alternatives have recently made their appearance, shellac is still the most important material in gramophone records. Shellac is also still extensively used in the electrical industry as a binder for mica-filled mouldings. It is at present in fairly short supply, and it has frequently been possible to use some of the ethenoid resins as an alternative.

UREA AND THIOUREA FORMALDEHYDE

Electrical properties	Good, non-tracking under electrical discharge
Mechanical properties	Excellent, bur affected by prolonged dry heat, and variable according to the filler
Usual filler	Cellulose

These materials have been known for an appreciable time, but it is only within the last fifteen years that they have been extensively developed on a commercial basis particularly for electrical work. For domestic use they are extremely popular on account of the number of pleasing and at'ractive colours available, and electrically they are valuable on account of their resistance to the formation of a conducting carbonised path (known as tracking) when subjected to electrical discharges over their surface.

The urea and thiourea materials are used mainly for domestic articles, such as cups and saucers, and can usually be distinguished by their light pastel shades, which are not so readily obtainable in phenolic materials. They do not soften readily with heat, but are not always satisfactory for prolonged use in warm dry situations. A recent important development in urea compounds has been the production of transparent articles.

Another interesting development is that the material has recently been produced incorporating solids that make it luminous in various colours after exposure to ordinary daylight. Switch-knobs, clock-faces, and so on, moulded in this material would obviously have considerable advantages over those made of other moulding-materials now available. Unfortunately the new material is rather expensive at present, but it is probable that either only a surface-facing of the luminous powder would be required or only a portion of the complete article need be luminous.

It is also possible to incorporate materials that give fluorescence when articles are exposed to ultra-violet rays. This is taken advantage of in aircraft design, since even the small glow from a pilot-lamp might tend to blind a pilot during night-flying, and the figures on instruments are therefore made from suitable powders, which become fluorescent when subjected to the action of ultra-violet light. They are illuminated by small black-light blubs, which in effect incorporate a filter allowing only the ultra-violet rays of the spectrum to pass, so that the figures glow, and the risk of glare is eliminated.

A CONCLUDING NOTE

Many plastics are used as bonding media to produce laminated materials, for example the products known in the electrical industry as Bakelised Paper insulators, which are in effect layers of paper cemented together by means of resin. It is also possible to bond together thin layers of wood, which are then highly compressed, and are used extensively in the manufacture of temporary jigs and the like, for which their durability and ease of machining are greatly appreciated, in addition to their lightness compared with corresponding metal articles. Yet another use of plastics (which it has not been possible to deal with in detail) is in conjunction with polarised light for the detection of mechanical strains and the like. Detailed treatment of these and other aspects of plastics has had to be deli erately omitted because they are specialised subjects in themselves, the discussion of which would be quite impossible within the scope of this paper. A different kind of application (which again cannot be fully described for similar reasons) is in connection with the building-trade, where the use of synthetic resin cements has facilitated the production of veneered

wood and metal not only extremely attractive in themselves but also much cheaper than corresponding materials produced in other ways.

It is hoped that the paper may have been of assistance in giving some general idea of the use of the materials of the various plastic groups. These are rapidly becoming increasingly popular, and it is difficult to visualise the ultimate scope of the industry, particularly as better-quality materials and improvements in technique are continually being developed.

Acknowledgements

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PART III

Appendices

Appendix A. Bibliography

The following very abbreviated selection from the voluminous literature on plastics is given as a basis for more extended study by those interested. The numbers in brackets indicate references in the text.

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(9) Bragg, *Journal I.E.E.*, 1935, vol. 77, p. 737.

(10) *The Chemistry of Synthetic Surface Coatings*, (Krumbhoar) : New York, 1937) : see also Bevan, *Chemistry and Industry*, 1942, vol. 61, p. 261.

(11) See various Technical Papers issued by the London Shellac Research Bureau.

(12) *The Fundamentals of Fibre Structure* (Astbury : Oxford, 1933) : see also Alexander, *Industrial and Engineering Chemistry*, 1939, vol. 31, p. 631.

(13) Mayer, *Chemistry and Industry*, 1938, vol. 57, p. 439.

(14) *Modern Synthetic Rubbers* (Barron : London, 1942) : *Rubber and its Uses* (Fisher : New York, 1941).

(15) *Properties of Glass* (Morey : New York, 1938).

Appendix B. A Classification of the Main Industrially-Useful Plastics

The number of trade-marks and trade-names in the plastics industry is very large, and is in a constant state of change and development : and it is impossible to quote here more than a representative selection as examples of each class. The majority of the names quoted are British or American, with a few German and other Continental examples.

Two main contractions are used in the classification. TP indicates that the materials consist of *chain-molecules*, and are therefore *thermoplastic* in their final fabricated state, whereas X indicates materials converted wholly or in part during processing to the fabricated state into *cross-linked molecules*, because they are either *thermo-hardening* or *element-convertible*.

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Group A—Of Wholly Natural Origin

MINERAL :
    (i) Bitumen, tar, pitch, asphalt (e.g. Gilsonite, Rafaelite)   TP
    (ii) Waxes (e.g. ozokerite, paraffin wax)   ...   ...   TP
    (iii) Clay   ...   .   —

ANIMAL :   ...   .   TP
    (iv) Waxes (e.g. beeswax) ...   .   TP
    (v) Casein materials (e.g. Erinoid, Galalith, Lactoid, Lanital)   ...   .   pseudo-TP
    (vi) Shellac   X

VEGETABLE :
    (vii) Gums and resins (e.g. amber, colophony, copal, kauri) ...   .   TP
    (viii) Drying oils (e.g. linseed, oititica, tung)   X
    (ix) Unvulcanised rubber latex   ...   ...   pseudo-TP
    (x) Protein materials (e.g. soya-bean, zein)   ...   pseudo-TP

Group B.—Natural Chain-Polymers, Modified Chemically

    (i) Cellulose esters, such as cellulose nitrate (e.g. Cellu-loid, Pyroxylin, Xylonite), cellulose acetate (e.g. Bexoid, Celanese, Cellastoid, Cellamold, Rhodoid, Tenite I), and cellulose acetobutyrate (e.g. Tenite II)   TP
    (ii) Cellulose ethers, such as methyl cellulose (e.g. Cellofas, Rhomellose, Tylose), ethyl cellulose (e.g. Ethocel), and benzyl cellulose   ...   .   TP
    (iii) Soft vulcanised rubber (e.g. Cabtyre)   X
    (iv) Hard vulcanised rubber (e.g. ebonite, vulcanite Becolite, Keramot, Stabec, Stabilite)   X
    (v) Chlorinated rubber (e.g. Alloprene, Detel, Tegofan, Tornesit)   ...   .   TP
    (vi) Rubber hydrochloride (e.g. Pliofilm)   ...   ...   TP
    (vii) Cyclised rubber (e.g. Pliolite, Thermoprene)   ...   TP
    (viii) Oxidised rubber (Rubbone)   X

Group C.—Of Wholly Synthetic Origin

    (i) Phenolic, Novolak-type (e.g. Novolak)   ...   ...   TP
    (ii) Phenolic, Bakelite-type (e.g. Bakelite, Catalin, Durez, Elo, Formite, Haefelyte C. Hy-Ten, In-durite, Keebush, Lithcote, Lorival, Mouldesnite, Mouldrite PF, Nestorite, Redmanol. Rockite, Texolex, Textolite, Tynolex)...   X
    (iii) Phenolic, modified (e.g. Albertol, Amberol, Crest-anol, Paranol)   X
    (iv) Urea and thiourea (e.g. Beetle, Cibanoid, Mouldrite UF, Plaskon, Pollopas, Scarab)   X

   (v) Melamine (e.g. Melapas, Melmac, Ultrapas)...   ...   X
  (vi) Aniline (e.g. Cibanite, Iganil, Panilax)   ...   TP : also X
 (vii) Alkyd
      (a) Polyesters and modified polyesters (e.g. Alkydal, Beckacite, Beckosol, Celestol, Dulux, Duraplex, Glyptal, Paralac, Paraplex, Rezyl)   ... X : also TP
      (b) Polyamides and modified polyamides (e.g. the Nylons)   ...   .   TP
(viii) Ethenoid
      (a) Polyolefines (e.g. Alkathene, Isolene, Oppanol, Polythene, Teleothene, Vistanex)   ...   ...   TP
      (b) Polyindene and polycoumarone (e.g. Cumar, Nevindene) ...   .   TP
      (c) Polystyrene (e.g. Distrene, Polytex, Resoglaz, Rhodolene, Styron, Trolitul)   ...   .   TP
      (d) Polyacrylic esters (e.g. Acryloid, Plexiglas, Plexigum, Plextol)   ...   .   TP
      (e) Polymethacrylic esters (e.g. Diakon, Lucite, Perspex, Pontalite)...   ...   .   TP
      (f) Polyvinyl chloride (e.g. Flamenol, Koroseal, Telcovin, Vinilyte Q. Vinyon, Welvic) ...   ...   TP
      (g) Polyvinyl acetate (e.g. Gelva, Mowilith, Vinnapas, Vinylite A)   ...   .   TP
      (h) Polyvinyl chloride-acetate (e.g. Astralon, Igelite, Mipolam, Vinylite V)   ...   .   TP
      (i) Polyvinyl acetals (e.g. Alvar, Butacite, Butvar, Formex, Formvar, Vinylite X) ...   .   TP
      (j) Polyvinyl alcohol (e.g. Resistoflex)   ...   ...   TP
      (k) Polyvinylidene chloride (e.g. Saran)   ...   ...   TP
      (l) Miscellaneous polyvinyls (e.g. ketone resins, Luvican)   ...   .   TP
      (m) Polydienes (e.g. Buna 85, Buna 115, Ker)   ...   X
      (n) Polydiene co-polymers (e.g. Buna N, Buna S, Butyl Rubber, Chemigum, Hycar, Perbunan)   X
      (o) Polyhalodienes (e.g. Neoprene, Sovprene)   ...   X
  (ix) Olefine-polysulphide (e.g. Perduren, Thiokol, Vulcaplas) ...   .   TP : also X
   (x) Sulphonamide (e.g. Santolites)   ...   ...   TP : also X
  (xi) Chlorinated hydrocarbon (e.g. Aroclor, Arubren, Clophen, Halowax, Nibren, Seekay)   ...   ...   TP
 (xii) Miscellaneous inorganic (e.g. glass, Eutex, Mycalex)   TP

Appendix C
Approximate Properties of Moulded Plastics

Follows on next page.

Appendix C. Approximate Properties

MATERIAL	Electric strength (kV/cm)		Power-factor at 50 cycles per second			Specific inductive capacity at 50 cycles per second
	15°C.	90°C.	*15°C.	60°C.	90°C.	
Aniline formaldehyde ... ... (a) unfilled ... ... (b) paper-filled	 140 200	 100 140	 0.01–0.02 0.02–0.06	 — —	 0.02–0.12 —	 3–4 3.5–5
Bitumen, mineral-and-fibre-filled	500	167	0.02	0.05	—	3–5
Casein	40	—	0.05	—	—	7.5
Cast resin (phenolic)	160	—	0.025–0.20	—	—	5–10
Cement, asbestos filled	20	20	—	—	—	—
Cellulose acetate	315	250	0.065	0.04	0.08	6
Ethenoids (a) Polyethylene ... ... (b) Polymethyl methacrylate (c) Polystyrene ... ... (d) Polyvinyl acetate ... ... (e) Polyvinyl chloride ...	 400 340 330 180 140	 — — 270 — —	 0.0003 0.07 0.0001 0.01–0.015 0.02	 0.0003 0.16 0.0001 — —	 0.0001 0.40 0.02 — —	 2.3 2.8 2.5 2.7 3.0
Lead borate, mica filled ...	240	190	0.01	0.01	0.01	6–8
Melamine formaldehyde asbestos filled	170	150	0.156	0.164	0.217	10
Phenol formaldehyde (a) mica-filled ... ... (b) high-quality-cellulose-filled (c) flaked-cloth-filled	 230 200 95	 200 100 20	 0.02 0.045 0.3	 0.052 0.125 —	 0.09 0.38 —	 5 6 7
Rubber (hard)	300	200	0.05	0.09	0.15	4
Shellac, mineral-and-fibre-filled	160	—	0.004–0.04	—	—	2.75
Urea formaldehyde, cellulose-filled (general-purpose) ...	120	75	0.038	0.12	0.40	6

*The values given are derived from specimens 1½ in. square by ½ in.

of Moulded Plastics

			MECHANICAL AND PHYSICAL PROPERTIES				
Specific gravity	Tensile strength (lb./sq. in.)	Compressive strength (lb./sq. in.)	Cross-breaking strength (lb./sq. in.)			*Moisture-absorption (per cent)
			15°C.	60°C.	90°C.	
1.22 1.34	8,500–10,000 14,000	23,000 35,000	14,000–17,000 25,000	— 24,000	— 23,000	0.05 0.22
1.3	1,100	8,000	3,000	—	—	Nil
1.35	7,600	—	5,000	—	—	2
1.27–1.32	8,300	17,000	12,000	—	—	0.1–0.5
1.5–2	3,400	13,500	9,250	8,700	8,400	12
1.27–1.37	3,500–10,000	11,000–27,000	14,000	—	—	1
0.92–0.94 1.18 1.05–1.07 1.2 1.2–1.35	1,350–2,400 4,000–6,000 5,500–8,500 5,000 4,000	— — 10,000–15,000 13,000–13,500 —	— 14,000 6,500–8,000 — —	— — — — —	— — — — —	Nil 0.1 Nil Nil Nil
3.0	5,000–8,000	13,500	12,000	12,000	—	Nil
1.98	5,900	—	8,000	—	—	0.2
1.6–2.09 1.25–1.52 1.37–1.40	5,000 7,000 6,500	16,500 34,000 34,000	5,000 10,000 13,500	5,000 9,500 10,500	4,500 8,500 9,250	0.05 0.3 0.4
1.1–1.8	7,000	8,600	9,000	—	—	Nil
1.1–2.7	900–2,000	10,000–17,000	600–1,000	—	—	0.5
1.45	9,000	26,000	8,500	4,900	4,000	0.3

thick after immersion in distilled water for 24 hours at 15°C.

Discussion

MR. SCOTT : I hope after hearing the lecture tonight, it will cure any of you who had ideas about entering the Plastic world, and deter you from carrying out that project. I am sure it is a very complex subject. I think the only thing that our lecturers tonight have missed out was Vitamins A. B. C. and D.

It has been a wonderful lecture from my point of view, and I have no regrets in having asked at the beginning of our session for a paper on Plastics. I am now going to open the meeting for discussion, but there are one or two things I cannot quite understand, and which I would like to ask the lecturers.

As an opening, I do not understand how they apply the heat to the various powders used in the manufacture of all the different kinds of plastics ; their diagrammatic lantern slides omit that very important thing to a meeting of engineers. How do they apply the heat apart from the electrical application ?

As a steel founder, and an iron founder, and several other kinds of founder, I am delighted to know that they are troubled with the question of shrinkage. That is a real bone of contention, and a subject for trouble. I am glad they have got some troubles on this production.

On one of the diagrams they mentioned the simple application of " wood flour." Do I take that to be a very minute form of sawdust, or what is " wood flour." ?

Then they used the term which in engineering I do not quite know, and that was " curing." Is that some form of heat treatment, or is it the question of the dissemination of heat, after the casting or pressing process ?

They are just a few points which I would like to ask Dr. Richie and Mr. Kirkwood, and I now open the meeting for discussion.

MR. WEBB : Talking about Fillers : Has a metal filler been used in conjunction with this thermo-plastic material, more especially with a thermo-setting, and if it is possible to use it, what would be the effect of high-frequency on it ?

MR. KIRKWOOD : In reply to the questions which Mr. Scott has raised. The first was the application of heat to the powders.

I am sorry that I omitted to mention this ; I should have made it clear that the heat is usually applied by means of the platen in the compression-type moulding. The powder is pressed between two hot platens. You have the two hot platens coming down, and these are heated by steam, because you get a much more even heat with steam than with electrical heating, and they transmit the heat to the powders through the mould itself.

Sometimes with a long moulding you do apply supplementary heaters, and you have in some of the thermo-plastics heat applied by circulating steam in the mould itself, but the usual way is by means of top and bottom platens.

On the question of shrinkage : When you are dealing with 14% and you have cooling from the outside, you probably know it is just hopeless to get over. You have got to arrange to have a forced feed into the centre of you article, otherwise you just find a great cavity in the middle.

On the question of Wood Flour : This is really any good quality wood—I think usually birch—but other woods are used. The main thing is that it must be ground very fine and it must also be dry and have no conducting particles, or any other impurities present.

On the question of " Curing " It is simply polymerisation, but I thought you would prefer " curing." It simply means you change your resin from the " B " to " C " stage, that is from the liquid stage to the final hard state. In other words, you get your linking of molecules complete. Curing is just a development of cross-linking.

In reply to Mr. Webb's question on Metal Fillers : It could be done, and is done, but mostly in the decorative trade. There is a material known as " Lustrene," on which I believe you get a very beautiful effects by using a bronze or aluminium powder, and you get a very nice-looking article.

You also mention the effect of high frequency. You would get heating, but at the same time I believe that the dust cores that are made in certain cases have a small core or binder. They mix the iron particles with a binder, and they use that for forming these dust-throwers, and the effect then of the binder is to prevent the circulating currents. This is the only application, apart from the decorative trade.

DR. RITCHIE : I was at the Leipzig Fair in Germany a few years before the war, and they showed me a special type of rubber, which was filled with a very finely divided colloidal metal, instead of the usual filling, the reason being to give a conducting rubber. There was a particular application where they wanted something flexible and elastic, and that had sufficient conductivity. I forget what it was called, but it was a German material, and they started with the colloidal state.

MR. SWALLOW : I would like to know what tensile strength this material has, and also what Izod, and how this material could be developed for making into gears. I have seen gears made of it, but mostly they have been cut after they have been cast.

One other question : On the bakelite, the thermo-formaldehyde structure, when that has been cast, can it be limited or can the

styrene be limited. I understand there is a slight difference between the two materials.

MR. KIRKWOOD : On the question of tensile strengths, that varies enormously. With formaldehyde you get a tensile strength of about 6,000 lb./in 2, and from the ordinary wood-filled, you get about 9—10,000 lb./in 2, but when you get this material pulling you get up to 20—25 lb./in 2.

With Izod I think the figure is about 0.6 foot lb. for the ordinary phenolacs, and it can go as high as 10 foot lb. for the flake fabrics, when you are heating it at right angles to the lamina. On the question of scrap I will ask Dr. Richie to reply.

DR. RICHIE : This question of the re-heating of scrap. It depends just on these two principles I gave you. If you have got a thermo-plastic material, you can grind your scrap and use it again.

Thermo-hardening material is not reversible ; you have completely cured or cross-linked it, and it is just scrap. You can grind it, but it does not soften again, unless you grind it fine and use it as a filler. With materials like Styrene and Perspex, you can grind your scrap and use it again because it is thermo-plastic.

Also, because of the fact that it is soluble, you can dissolve it and use it as a varnish, laquer or adhesive.

Again, you cannot do that with the thermo-setting materials because they have lost not only their thermo-plasticity, but also their solubility.

Your thermo-hardening scrap is just scrap, but your thermo-plastic scrap can be re-used as a moulding powder, or as a laquer, varnish or adhesive.

MR. WEBB : If I may just take our friend's question a stage further. Has ageing any effect on its mechanical properties ?

DR. RITCHIE : In some materials the effect of ageing is quite marked. Mr. Kirkwood mentioned very briefly that if you keep the thermo-formaldehyde materials in a dry atmosphere they lose a small proportion of moisture, which is an essential part of the material to keep it firm and tough. If you age them in a very dry atmosphere they lose a small amount of water and become brittle.

Again, it all depends on exactly what you mean by " ageing." If you mean heating, then practically all the materials lose some mechanical strength as you raise the temperature.

If again you simply mean exposure to the atmosphere, things like the Phenolacs are hardly affected, but materials of the rubber or ebonite class are affected, because in the presence of strong sunlight or of ozone produced by electrical discharge, you get first an attack on the rubber which embrittles it, and in the second place this has an important application.

In some cases you get oxidisation of the surface of the rubber, which causes surface leakage, so that it is impossible to give one complete answer to your question.

Most of the mechanical properties are not affected, but the Ureas may lose strength, and the rubber may become slightly brittle, particularly where there is strong sunlight on the rubber, or it is anywhere near an electrical discharge.

MR. TEMPLE : In using thermo-hardening material, is it necessary to weigh out the exact quantity of the powder in every case, or if you do not, how do you control the point between the powder and the thermo-hardening stage.

MR. KIRKWOOD : You do weigh up the charge, particularly for electrical moulding where you have a positive charge in the mould. You have got to compress everything you put into the mould, and and you must weigh it very accurately.

In the case of flash mouldings you need not be so exact ; the moulding really closes to a small point, and any excess over the normal charge can be ejected between the two points until the two moulds close. Of course, if you are very inaccurate you waste your material.

MR. SWALLOW : I would like to know if it is possible to make a mould to cast a gear. In the first place, a straight gear ; if that is too easy, would it be possible to make a mould to cast a spiral gear ?

Following my other question on the tensile strength, am I right in saying that the tensile strength can be got up to about 10 tons ? If, as was suggested, linen or cotton inserts are put in, how is the linen or cotton kept from decomposing with the heat whilst it is being compressed ?

MR. KIRKWOOD : Actually it is possible to make a mould for a gear wheel. I think it is fairly straightforward. A simple compression-type mould would do it.

In connection with a spiral gear, you could still do it ; you might have to use transfer moulding to get the pressure, but it is still quite an easy proposition, there is no difficulty at all. In fact, you could even include a brass bush in the centre for keying on to the shaft.

In connection with decomposition, the temperature which we use is only about 150°C., so there is no danger of decomposition. We pre-heat the powder to 80 or 90° and at 150°C., the resin begins to flow and form, and that is pressed in the mould, but no decomposition takes place at that temperature.

DR. RITCHIE : Again it depends on the length of time you expose it. If you take a linen fibre and maintain it at 150°C. you will gradually over a period of days, get a falling-off in the tensile strength, but you will not get any measurable effect in your 2-minute moulding time at 150°C. On a 2-minute moulding cycle you would

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have to take a linen fibre up to 350°C. before you got decomposition.

MR. SEED : Mr. Kirkwood mentioned in the course of his lecture the use of plastics for blanking aluminium dural. What group does that belong to, and when the edge, which I presume will crack, does eventually do so, how is it repaired ?

Another thing : is there any trouble in the building up, due to the aluminium being rubbed into the material ?

MR. KIRKWOOD : I have given you right up-to-the-minute information. This thermo-cast which I mentioned has only just become available within the last two months. It is an American development, and is a thermo-plastic.

It is Ethil-cellulose, and is melted at about 200°C. and cast, and you get a very small shrinkage, and you need a light machine to get the final dimension accurate.

On the question of rubbing I do not know, but I should imagine it is so cheap that once it chips you just melt it down and re-cast it, but as I have said, these details have only just become available, and I have had no experience with this material.

MR. HOLMES : What is the effect of minus temperatures on plastics ?

MR. KIRKWOOD : Electrically I think you will come to a stable value. When you have got thermos in the article, you will come to a temperature of about —100 to the limiting factor of the impulse strength, but from the mechanical aspect I do not think you will have a great deal of difficulty. You would have shrinkage and the thermo-plastics become brittle, and that is one of the advantages.

There is a big controversy going on in the aircraft industry, as to whether cellulose acetate is better than perspex, but perspex has won.

Rubber Ebonite is not much affected. I have not had it lower than —70° but I have had ordinary flexible rubber down to that temperature, and it does harden and become brittle, but generally speaking it will not be seriously effected.

Your Cellulose Acetate will definitely brittle up, otherwise these materials will be reasonably stable. They are used for high-altitude flying because they retain their characteristics at low temperatures.

MR. HOLMES : Does shrinkage continue below zero ?

MR. KIRKWOOD : Yes.

MR. PERKS : Dr. Ritchie spoke of rubber as being a plastic. I saw some time ago in London a piece of rubber about 12 in. long made in three portions, red, white, and blue, and they said it had been welded in one piece. What process would be used ? You made very clear the question of the two principal divisions, thermo-settings and thermo-plastics. Is it possible to have a

standardisation of these names such as we have in steel specifications, so that when a job goes into the shops, or on to a machine, the operator is not confused by long names, but has some simple classification such as, for example, THS2.

I also see on the table some dentures, and there are some people in Newcastle who are interested in this manufacture. I would like to know if those have actually been made in this country.

MR. SCOTT : Before Mr. Kirkwood answers, I think there is Mr. Holmes' question of minus temperatures.

MR. KIRKWOOD : I should have mentioned one very important point. At low temperatures be careful of the relative shrinkage of your metal and you moulding, otherwise you will have a cracked moulding.

DR. RITCHIE : I would like to answer two of Mr. Perks' questions. With regard to the welding of rubber. Are you quite sure it was natural rubber and not synthetic rubber ?

MR. PERKS : It was Synthetic Rubber.

DR. RITCHIE : There is a material called " P.V.C." It flows and is of a syrupy consistency. If you take that and put it in a test tube and heat it to 150° for a quarter of an hour, you can cast it and weld it together, provided the section is not too thick. You can weld them together with a hot iron. Welding is quite a good description, and the fact that you have mentioned two or three different colours makes me think that was what was done.

On the question of the dentures : They are made by every dental surgery in the country. The dental plate is made of the same material as the aircraft gun turrets. but properly pigmented, and they can be made entirely in this country.

The dental profession has been recently instructed that after their present stocks of vulcanite are used, no more can be made because it is imported. There will be no more vulcanite dentures made until after the war, but I very much doubt if even then the trade will go back to vulcanite because perspex is so much lighter.

MR. KIRKWOOD : I do not think you can classify the plastics— it would be very difficult. You could set the process, but it does not matter to the man in the moulding shop whether it is a thermo-setting or a thermo-plastic.

MR. PERKS : I am thinking more of the machining. Surely you would not state, for example " drill two holes in . . . some long name . . . Would it not be better to say " drill two holes in say T.H.S.2."

MR. KIRKWOOD : A certain system has been adopted. In a large firm you cannot specify on a drawing the actual material, because you have such things as standard lists and standard opera-

tions, and once you tie yourself up by mentioning a name on a drawing, you tie yorself up for every afterwards, and if you get an improvement you cannot readily change.

What has been done is that you group the material according to its properties. You have, say, dielectric strength 1, 2, 3, and 4. You set the limits between 5 and 10 kV—1, 10 and 15—2, and so on. When the draughtsman calls for the article, he simply calls for a series of numbers according to the properties he wants, and that is specified on the drawings to an elastic system, allowing you to adopt any new material if you wish.

This system has been in operation for about 10—15 years, and has proved very practical.

MR. GARLICK : Is it possible, owing to the lightness of this material, to deposit chrome on such hard material, mainly for use in gauges.

One of the big troubles to-day is the weight of certain gauges, particularly large ring gauges, and plug gauges. Strides are being made in glass, but the big trouble there is that they scratch, and I think a big advantage in bakelite is the low co-efficient of expansion.

DR. RITCHIE : There are several processes for electrically plating metals on to plastics. They are mostly proprietary processes, and you have to get hold of the patent rights to do it, but they all depend on coating with some conducting layer of graphite, and you electrically plate on to that.

There are all sorts of decorative finishes where you get a plastic finish, partly coated with metal but electrically plated. I cannot remember the names of the people, but I could get them if you are interested—it is certainly a feasible proposition, and you can do it with chrome.

MR. SCOTT : I feel that tonight we have had one of the most interesting lectures since the inauguration of the North-East branch, and I am more than ever delighted that the lecture has been given by two of our local engineers. I am very pleased that this lecture has taken place. It confirms my opinion that it would be valuable in increasing the general knowledge of engineering.

I am going to call upon Mr. Perks to express the thanks of this Institution to the Lecturers—Dr. Ritchie and Mr. Kirkwood.

MR. PERKS : Mr. President : I rise to propose a vote of thanks to Dr. Ritchie and Mr. Kirkwood. We heartily endorse all that our President has said. This is one of the most interesting lectures we have had, not only in the matter, but in the manner in which it has been delivered. It is satisfactory, too, that we have been

able to obtain our lecturers from the North-East coast. The subject with which they have dealt so ably is of such importance that the Institution have covered it in the higher National Certificate for Production Engineers. It is with great pleasure I call on the meeting to accord a hearty vote of thanks.

MR. KIRKWOOD : On behalf of Dr. Ritchie and myself I would like to express our pleasure in being able to give you this short talk, and our apologies that we have had to cut so much out, but I think we have got through quite a lot.

Research Department :
Production Engineering Abstracts
(*Edited by the Director of Research*)

NOTE.—*The addresses of the publications referred to in these Abstracts may be obtained on application to the Research Department, Loughborough College, Loughborough. Readers applying for information regarding any abstract should give full particulars printed at the head of that abstract including the name and date of the periodical.*

HARDENING, TEMPERING, ANNEALING.

The Quenching of Gears for Heat Treatment. (*Mechanical World, 3rd March, 1944, Vol. 115, No. 2983, p. 231, 3 figs.*).

The function of the quenchant. Quenching considered as a three stage process. (1) the vapour stage, (2) the vapour transport phase, and (3) the conduction and convection stage. Importance of the uniformity of cooling. Significance of the temperature gradient set up. Rate of cooling and desired structure. Choice of a quenching medium. Employ the least drastic quench which will give the desired physical properties. . Properties of an oil found eminently satisfactory for most purposes. Mechanical quenching machines for heat treated gears which forcibly retain the shape of components during quenching. Two popular types. Die design. Die quenching practice. Difficult shapes. Quenched with an error of less than 0.001 in.

COMBUSTION, FURNACE.

The Uses of Controlled Atmospheres in the Metal Industries, Part V. (*Sheet Metal Industries, February, 1944, Vol. 19, No. 202, p. 243*).

This part, which deals with ferrous metals, completes the series.

(*Communicated by the British Non-Ferrous Metals Research Association*).

Coil Design for Successful Induction Heating, by F. W. Curtis. (*The Machinist, 18th March, 1944, Vol. 87, No. 48, p. 83, 5 figs.*).

Induction coils either of multi-turn design, or in the form of a single-turn coil. Heating metal parts is the result of internal energy losses within the material being treated. With ferrous materials, having magnetic properties, these losses are through hysteresis and eddy currents, up to the curie point, where magnetic properties cease to exist, and from there on (about 1400°F.) heating is due only to eddy-current losses. With non-magnetic materials, the only losses present are eddy-current losses so that the induction of heat into such parts requires more time. Single-turn coils, close coupling and loose coupling. With multi-turn coils a closely wound coil and rotation of the workpiece become essential. Coil acts as the primary winding of a transformer. Its design affects the degree of induction in the workpiece. Coils vary in size and shape according to the uses to which they are put. Irregular shapes are resorted to when the nature of the work calls for them. The field strength depends in the design of the coil and its method of application. Shapes include : round, rectangular,

formed, pancake, spiral-helical, internal. Particularly care must be taken in forming coils for internal work since the heating effect is inherently slower than for external work. Cross-sectional shape of the coil tubing and method of support are additional considerations.

The Theory and Practice of Industrial Electronic Heating, by J. P. Jordan, (*Gen. Elec. Rev., December, 1943, Vol. 46, No. 12, p. 675*).

Mainly an account of the theory of induction heating of metals and dielectric heating of non-metallic materials, with a short note on equipment.

(*Communicated by the British Non-Ferrous Metals Research Association*).

COOLANT, LUBRICANT.

Cutting Oils—Their Purposes, Properties and Application, by E. V. Paterson. (*Mechanical World, 10th March, 1944, Vol. 115, No. 2984, p. 257, 12 figs.*).

Early cutting fluids. Qualities required by a cutting fluid. High thermal conductivity. Good wetting properties and adherence. Lubrication of the tool and chip. Transparency. Chip removal. Freedom from obnoxious smells. Free from producing dermatitis or skin diseases. Stability. Reasonably high flash point. Low viscosity. Dangers of corrosion. Tests for resistance to corrosion. Soluble or straight oils. Lubrication of slides, turret bearings, tool post, etc. Wear of expensive tools. Troubles experienced with soluble oils. Incorrect mixing. Machining steels that have been pickled with acid. Breakdown where different metal turnings are mixed together. Troubles experienced with straight oils. Application of cutting fluids. Special considerations. Brass and aluminium. Danger from fire. Gumming. Dry cutting.

ELECTRICAL ENGINEERING.

Small Motor Selection Guide—I and II, by H. Welch. (*The Machinist, American Machinist Reference Book Sheet, 25th March, 1944, Vol. 87, No. 49, p. 113, 23 figs.*).

Selection of fractional-horsepower motors. Seventeen types are grouped in three categories—alternating current, direct current and universal. The characteristics curves are presented and the wiring diagrams with tabulated information.

EMPLOYEES, WORKMEN, APPRENTICES, ETC.

Mechanics of the Exit Interview. (*Personnel, U.S.A., January, 1944, Vol. 20, No. 4, p. 231, 2 figs.*).

Experience in both private industry and governmental agencies has established the value of the exit interview as a reliable source of information for management action. Expertly conducted, this type of interview has frequently effected the retention of desirable employees on the verge of leaving. The paper discusses the steps leading up to the termination interview, methods of conducting the interview, and forms used in recording interview data.

Wartime Training Points the Way, by E. F. Wonderlic. (*Personnel, U.S.A., January, 1944, Vol. 20, No. 4, p. 256*).

The speedup in training methods necessitated by the war will have widespread repercussions in postwar industry. Indeed, the author predicts, workers who have been subjected to " quick training " procedures will be loath to undergo the lengthy apprenticeships prevailing in many trades before

the war. With particular emphasis on sales training, the author scrutinises training techniques and presents a simple formula for quick, progressive training.

FOUNDRY, MOULDING, PATTERNS.

Magnesium Foundry Technique, by I. Ross. (*Foundry Trade Journal, 3rd, 10th February, 1944, Vol. 72, Nos. 1433, 1434, p. 89*; *Discussion, 17th February, 1944, Vol. 72, No. 1435, p. 143*).

Describes the technique employed in the regular production of a very large Mg alloy casting, emphasising the need for close control of all details in melting, moulding, casting and finishing.

(*Communicated by the British Non-Ferrous Metals Research Association*).

The Injection of Metal into Die Casting Dies, by H. K. Barton. (*Machinery, 30th March, 1944, Vol. 64, No. 1642, p. 357, 3 figs.*).

Flow of fluid metals under pressure. Discussion of case of a die casting die having a plain rectangular cavity, into which a free-running jet of liquid metal is forced under constant pressure through a gate by Frommer jet. Direction and cross-section. Pulsating flow. Accumulation in the extreme end of the cavity. Filling period. Friction. Turbulence. Stability. Air. Brandt propositions. Changing shape of the jet. Comparison of theories. Variable factors. Injection rates. Variation of pressure during injection. Variations in pressure throughout the system.

Gravity Die Casting in Non-ferrous Alloys, by E. H. A. Carlton. (*Transactions of the Institution of Engineers and Shipbuilders in Scotland, March, 1944, Vol. 87, Part 5, p. 105, 9 figs.*).

Gravity die casting. Sand casting. Centrifugal casting. Hot stamping and pressing. Extrusion. Die design. Cores. Shrinkage allowances for the usual alloys. " Runners " and " risers." Sample casting. Die casting. Foundry furnaces. Green labour. Alloys in general use for die casting. Average casting temperatures. Filling the die without creating turbulence in the metal. Satisfactory surface of casting obtained by correct temperature of the die and correct consistency of dressing for the die surfaces. Patented die-coat for aluminium. Die life. Removal of " runners " or " risers." Inspection. Crack detection. Heat treatment of castings. Solution treatment. "Ageing." Laboratory and testing plant.

MACHINE ELEMENTS.

Heavy-Duty Bearings of Phenolic Plastics, by H. M. Richardson. (*Power Transmission, March, 1944, Vol. 13, No. 146, p. 186, 9 figs.*).

Phenolic-plastic bearings have been applied to practically all types of rolling mills. Bearings of this sort must have an adequate, dependable supply of cooling and lubricating water. When properly applied and water-lubricated they are very stable, long-wearing, and efficient. Outline of mounting for phenolic plastic bearings with water lubrication. The usual practice in the United States in the application of phenolic laminated roll-neck bearings is to take the existing bearing blocks or chucks and machine them out to accommodate a radial bearing lining. Various types of phenolic laminated roll-neck bearings. Four classifications : 1. Water lubricated bearings. 2. Grease-lubricated bearings. 3. Bearings subjected to heavy impact loads in intermittent service. 4. Oil-lubricated bearings with circulating-oil lubrication. Economies resulting from the use of phenolic

plastic bearings. Technical reasons for the success of phenolic plastic bearings. Friction curves for phenolic plastic bearings with water lubrication. Limitation of the use of phenolic plastic bearings.

MACHINING, MACHINE TOOLS.

Cylinder Boring, by Clifford T. Bower. (*Machine Shop Magazine, March, 1944, Vol. 5, No. 3, p. 47, 3 figs.*).

Boring liners of medium grade cast iron, finished length about 24 in., finished bore about 8 in. ; bore required to be straight, truly circular and parallel throughout its length, the tolerance not exceeding 0.002 in. Way of producing these liners with a minimum of tooling, a maximum of expediency and no interference with the general work of the plant.

Securing Fine Surfaces by Grinding, by H. G. Wills. (*Machinery, 16th March, 1944, Vol. 64, No. 1640, p. 294*).

Distinction between dressing and truing. Dressing tools. Action for dressing roughing and semi-roughing wheels. Locked-disc type. Dressing with abrasive stick. Proper use. Diamond dressing tools. Grey and white bort stones. Brown bort stones. Diamond shape. Useful dressing points. Determining the size of diamond for various kinds of dressing service. The personal element. Holding the diamond in the tool. Determination of the time for resetting. Matrices. Dressing tools with several diamonds. Tools having from three to seven small stones. Recent development.

Troubles Encountered in Internal Grinding, by E. T. Larson. (*Machine Tool Review, January-February, 1944, Vol. 32, No. 189, p. 21, 3 figs.*).

Bell-mouthed hole. Feed lines or spirals. Tapered instead of straight hole. Out-of-round hole. Chatter marks. Scratching of work. Burning or checking of work. Vibration or overheating of wheel head. Belts. Uneven table motion on hydraulic table traverse grinders. Wheel truing and dressing. Wheel loading. Wheel glazing. Wheel breakage.

High-Speed Milling, by Paul Dubosclard. (*Mechanical World, 3rd March, 1944, Vol. 115, No. 2983, p. 237, 4 figs.*).

Woodworking methods applied to light alloys. Account based upon the performance of about 80 machines. Theoretical considerations. Factors are : (1) The area of possible fracture of the cutter, (2) The area of desired fracture of the work, (3) The shearing strength of the cutter material, (4) The shearing strength of the work material, (5) Specific gravity of cutter material, (6) Specific gravity of the work material. Description of spar-milling machine with reasons for construction adopted. Bed. Steel of complete box-type construction. Welded and stress-relieved. Hydraulic clamping. Carriage of steel, welded, stress-relieved, box-construction. Each milling head connected to a cam follower which rolls along a suitable template. Milling heads, running at a speed of 3600 r.p.m. Super-precision, spring-loaded ball bearings. Motor rotor directly mounted on the spindle. Oil-vapour lubrication under positive air pressure. Operating-results ; horsepower. Gradually stepped up to 20, 30, 40 h.p. per head without any trouble. 2.5 to 4 cu. in. of metal removed per h.p. per min. Spindle speeds. The author advocates the use of large cutters rather than super-high spindle speeds (over 3600 r.p.m.). Feed speeds determined by the available horse power, and the cross section of the cut. Examples. Vertical spindle versus horizontal spindle. Horizontal spindles, using slab cutters, should give the best results.

Optical Munitions. (*The Australasian Engineer, 8th November, 1943, Vol. 43, No. 330, p. 50, 20 figs.*).

Substitute optical glass and camera lens manufacture in Australia. Overcoming immense technical difficulties, Australia began making her own optical munitions soon after the outbreak of war. The industry was quickly established, and Australia is now producing between 100 and 150 types of instrument. Substitute optical glass obviated the immediate need for optical glass ,and allowed the work to go on. Layers of best quality polished, quarter inch plate glass were welded together, making substitute optical glass. Camera lens. Design and computation. The working of spherical surfaces. Mounting and assembly.

The Design of Stampings for Quantity Production. (*Machinery, 23rd March, 1944, Vol. 64, No. 1641, p. 319, 28 figs.*).

Simple rules to ensure that production is simplified. Cost and size. Size and shape of blank. Thickness of stock. Type of material to be selected. Cutting to reduce waste stock to a minimum. Bends and folds parallel with grain of metal. Bends across grain of metal. Inside radius of bends. Sharp corner. Radius at the bottom of drawn cup. Inside radius too small. Flanges. Practice recommended : connecting radii ; inside corner radii ; outside radii ; depressions and pads ; depth of draw ; deep drawing. Shape of drawn parts. Draw without wrinkles. Deep-drawing of irregular shapes. Parts requiring drawing or forming operations over a portion of their area. Methods used in producing corrugations. Formation of stiffeners. Use of flexible rubber punches for forming irregular shapes.

Design and Production Technique. III. Principles Involved in Punching, by A. J. Schroeder. (*Aircraft Engineering, March, 1944, Vol. XVI, No. 181, p. 83, 103 figs.*).

Three principal points : (1) good and cheap material, (2) low production costs and (3) correct design. Sub-division of working methods :

Punching Technique

Bending.
Rolling.
Embossing.
Planishing.
Coining.

Production method depending on the number of pieces. Bending strain. Increased stresses during bending. Dangerous folding of shearing parts within the weakened cross section. Correct position of the bending axis. Gaps in bent parts to form a seating face. Influence of the rolling direction of material for bent parts. Manufacture of punching tools. Selection of tools. Shaping is decisive in reducing costs of tool manufacture. Subsequent treatment. Precision. Appearance. Exploitation of material. Existing equipment.

Development of the (Zinc) Pressure Die-Casting Industry, by H. Skelding. (*Met. Treatment, Winter, 1943-4, Vol. 10, No. 36, p. 249*).

An account of general organisation of methods for production of sound, reliable castings.

(Communicated by the British Non-Ferrous Metals Research Association).

XXXVIII

Band Sawing, Filing and Polishing, by J. H. Bird. (*Met. Treatment, Winter, 1943-4, Vol. 10, No. 36, p. 225*).

Outlines developments in combined band sawing, filing and polishing machines and discusses the training of operators.

(Communicated by the British Non-Ferrous Metals Research Association).

A Sampling Inspection Plan for Continuous Production, by H. F. Dodge. (*Transactions of the A.S.M.E., February, 1944, Vol. 66, No. 2, p. 127, 5 figs.*).

The plan of sampling inspection, described for individual parts, sub-assemblies, finished articles, and the like, is intended primarily for use in process inspection where there must be assurance that the percentage of defective units is kept down to a low prescribed figure. The system is particularly applicable to products manufactured by conveyor or similar straight-line continuous processes. The object of the plan is to establish a limiting value of " average outgoing quality " expressed as a percentage of defective units, which will not be exceeded no matter what quality may be submitted to the inspector.

Quality Control, by H. Howell. (*Aircraft Production, April, 1944, Vol. 6, No. 66, p. 198, 8 figs.*).

A review of three common misapplications of the system. Control limits by formula. Control limits by percentage defective. Gauges to control tolerances. Analysis. Application of system.

Magnetic Separation of Non-Ferrous Scrap, by H. H. Thompson. (*Metal Industry, 31st December, 1943, Vol. 63, p. 418*).

The author describes, with diagrams, British apparatus and practice. Magnetic separators of the pulley, drum, chute and magnet-chute types are dealt with, and the overband type employed for removal of iron from sand is also described.

(Communicated by the Nickel Bulletin).

MATERIALS, MATERIAL TESTING.

Residual Stresses in Metals, by W. Richmond. (*The Australasian Engineer, 7th December, 1943, Vol. 43, No. 331, p. 21, 9 figs.*).

Introduction. Nature of internal stress. Determination of residual stresses. Longitudinal stress. Transverse stress. Triaxial stresses. Stress in plates. Stresses in tubes, pipes, etc. Effect of residual stress. Relief of residual stress in castings. 1. cast iron. 2. Steel. 3. Gun-metal and high strength brass. Cooling after annealing. Cold working. Season cracking. Mercurous nitrate test. Caustic embrittlement. Stress relief of drawn bars, etc. 1. By heat treatment. 2. Stress relief by mechanical means. Residual stresses in nickel silver. Residual stresses in hardened steel. Generation of stress. Plain carbon steel. Oil quenched alloy steel. Stresses in tempered steel.

Further Developments in the Production and Technology of Magnesium and its Alloys, by F. A. Fox and G. Goddard. (*Metallurgia, December, 1943, Vol. 29, No. 170, p. 79*).

(Communicated by the British Non-Ferrous Metals Research Association).

Non-Destructive Testing of Non-Ferrous Semi-finished Metal Products by New Magnetic Induction Methods, by W. Schirp. (*E.T.Z., Germany, 12th August, 1943, Vol. 64, No. 31/32, pp. 413/414*).

The magnetic induction method for the inspection of non-ferrous metals depends on the fact that the apparent resistance of a coil fed with high frequency alternating current and surrounding the specimen varies with the dimensions and electrical conductivity of the latter. The method is primarily suited for tubes, rods or profiles of nominally constant cross-section which can be passed through the coil. Flow rates as high as 1 m/sec. can be maintained through the apparatus, which normally is provided with two test coils forming the opposite arms of a Wheatstone bridge. An EMF of sonic frequency is applied and the out of balance current after amplification can be observed on a cathode ray oscillograph and will operate an electronic relay as soon as certain limiting values are exceeded. The test process is completely automatic and does not depend on visual observation, special electronic relays being provided which automatically mark faulty sections of the tubes as they pass through the apparatus. A great advantage of the apparatus is the high speed of operation (over 1m/sec.) and the absence of skilled attention.

(*Communicated by the Ministry of Aircraft Production*).

Testing Armour-Piercing Bullets for Cracks after Manufacture. [*Z.V.D.I. (Germany), Vol. 88, No. 3/4, 22nd January, 1944, p. 54.*]

It is claimed that haircracks are rendered more easily visible if the hardened part is subjected to sudden changes in temperature. For this purpose, two water tanks are provided which are kept at 0° and 100°C. respectively. The parts are transferred from the cold to the hot tank several times and finally examined at room temperature.

(*Communicated by the Ministry of Aircraft Production*).

MEASURING METHODS AND APPARATUS.

A Method of Measuring the Thickness of Helical Involute Gear Teeth, by J. Reimer. (*Machinery, 9th March, 1944, Vol. 64, No. 1639, p. 266*). *3 figs.*).

Method independent of the outside diameter applied without removing the gear from the cutting machine. Simple, accurate go and not-go gauges. Spur gears. Helical gears. " Base rack." Tooth-thickness gauge. " Base Rack " for helical teeth. Derivation of dimensions. Modifications due to helix angle. Example.

Effective Control of Shop Gauges, by L. W. Macomber. (*The Machinist, 4th March, 1944, Vol. 87, No. 46, p. 97, 3 figs.*).

Under this system control starts in the planning department with one man assigned to plan and maintain its operation in the shop and gauge inspection areas. This man determines the number and type of gauges used in the department, orders new gauges, arranges for repairs of worn gauges, controls gauges in toolcribs, shop and inspection areas and controls movement of gauges to and from gauge inspection. In determining the number of gauges required to maintain production, allowances are made for periodic inspections. In determining the intervals of inspection, tolerances allowed and frequency of use must be considered. Records of all gauges and measuring tools on hand must be accurately kept and a chronological index maintained to a specific gauge will be picked up and inspected for wear or damage at the end of its prescribed interval. Typical file record card showing inspection dates and

location at various times. Colour charts giving codes used in marking gauges are posted in toolcribs, inspection areas, and used by supervisors so that proper colour for the period may be recognized. Any product design change that affects gauges is recorded on a " Change in Design Notice," copies of which are used as guides in changing all gauge records. Flow chart of three identical gauges through gauge control shows how each gauge must pass through the service section before it goes into use or storage.

METALLURGY OF IRON AND STEEL.

The Effect of Heat Treatment and Carbon Content on the Work Hardening Characteristics of Several Steels, by J. H. Hollomon. *(Amer. Soc. for Metals, Preprint, 14th October, 1943).*

The author summarises the work of Gensamer and of MacGregor on strain-hardening and reports original experiments on four types of steel. The results show that both increase in carbon content, and rise in tensile strength increase the rate of strain-hardening, irrespective of the microstructure of the steel. Mechanical strength and rate of work-hardening are the factors determining the tensile plastic properties of the steels.

(Communicated by the Nickel Bulletin).

Mechanical Properties of Austenitic Stainless Steels, by R. A. Lincoln and W. H. Mather. *(J. Aeronautical Sci., October, 1943, Vol. 10, No. 8, p. 253).*

Mechanical properties of 18:8 and other stainless steels ; effect of composition ; drawing and spinning properties ; effect of cold work ; properties of alloys in which part of the Ni has been substituted by Mn.

(Communicated by the British Non-Ferrous Metals Research Association).

PHYSICS.

Diamond Geometry, by Paul Grodzinski. *(Industrial Diamond Review, March, 1944, Vol. 4, No. 40, p. 49, 11 figs.).*

A link between the diamond and geometry is discussed. Geometrical properties of octahedron. Natural diamond octahedra. Historical survey. Patterns produced by various sections. $\sqrt{2}$ relationships and preferred number system.

PHOTOGRAPHY, X-RAYS.

Radiographic Inspection, by L. Mullins. *(Welding, March, 1944, Vol. 12, No. 4, p. 135, 9 figs.).*

Some fundamental theoretical points. X-ray generating equipment. Photographic materials and accessories.

Radiographic Inspection of Light Alloy Castings, by R. Taylor. *(Automotive and Aviation Ind., 15th November, 1943, Vol. 89, No. 10, p. 36).*

A general account of technique and uses.

(Communicated by the British Non-Ferrous Metals Research Association).

Microradiography—A New Examination Technique. *(The Commonwealth Engineer, 1st January, 1944, Vol. 31, No. 6, p. 149).*

Specimens a few thousandths of an inch thick. Radiograph enlarged up to 300 diameters must distinguish, for example ,between magnesium (atomic number 12), aluminium (13) and silicon (14), if they appear in separate

dispersed form. Technique. Principle. Light alloy specimens. Multiple radiation technique. Steels. Applications. Limitations. Advantages.

PLASTIC MATERIALS.

Plastics, by Martin Apley. (*Machinery-Lloyd, 18th March, 1944, Vol. XVI, No. 6, p. 37, 1 fig.*).

Main types of plastics. Thermo-plastic. Thermo-setting. Modes of manufacture. Cellulose plastics. Polymerisation. Thermo-setting resins. New materials and tools for the engineer. Compressed wood. Resin-bonded plywood. Expanded plastics. Bonding agents. Press tools and jigs. Drop hammer punches. Synthetic resin finishes. Future trends.

Plastics in War and Industry. (*The Australasian Engineer, 8th November, 1943, Vol. 43, No. 330, p. 66, 7 figs.*).

Phenomenal growth of ingredients, compounds and varieties. Kinds of plastics. Development. Plastics in automobiles and planes. Other industrial uses. Plastic printing plates. Cellophane for packaging. Production.

Physical Properties of a Structural Plastic Material, by C. W. Armstrong. (*Transactions of the A.S.M.E., February, 1944, Vol. 66, No. 2, p. 135, 5 figs.*).

Methods of laminating " no-pressure " resins. Physical test programme. Materials tested and methods of testing. Physical test results. Specific strength values. Discussion of results obtained. Costs of the processed materials.

RESEARCH.

Tool-Life Tests, by O. W. Boston. [*Mechanical Engineering (U.S.A.), February, 1944, Vol. 66, No. 2, p. 130, 2 figs.*].

This standard covers test methods for the appraisal of single- point cutting tools other than those of cemented carbide ; as carbide tools fail or wear somewhat differently from those of steel and cast non-ferrous alloys, a separate procedure for rating them is being developed. Suggested data sheet for cutting-speed tool-life tests in turning.

SHOP MANAGEMENT.

Aspects of Modern Foremanship. (*Production and Engineering Bulletin, March, 1944, Vol. 3, No. 16, p. 105, 4 figs.*).

The foreman as instructor. Duties and responsibilities. Direct training responsibilities. Ministry training centres. Training within industry. Ministry help. Systematic training. Requirements of a good instructor. Right conditions.

The Morale Function of the Executive, by LeRoy H. Kurtz. [*Personnel, (U.S.A.), January, 1944, Vol. 20, No. 4, p. 202, 7 figs.*].

Organisation morale operates from the top down. Only enlightened leadership in action can produce the *esprit de corps* that distinguishes the alert, aggressive, continuously advancing army, party or business institution. Maintenance of executive efficiency. Critical attitude needed. Application of the curve of growth. Executive qualities. Executive techniques. Executive results. Future value. Age—present age and years to go. Health tendency. Adaptability—for other assignments. Driving power. A measurement of executive progress. Methods of dealing with the problem executive.

SMALL TOOLS.

Recommendations for the Use of Diamond Turning Tools. (*Industrial Diamond Review, March, 1944, Vol. 4, No. 40, p. 60, 9 figs.*).

I.D.R. data sheet and " pin-up " page No. 3 (new series). General considerations. Tool edge. Machines absolutely rigid without vibration, on a solid foundation. Driving motor mounted separately. Spindle well balanced. Bearings properly fitted and free from play. Tools clamped rigidly. Rotating tools properly balanced. Tool edges. Point angle. Tool shape. Side adjusting angles. Clearance angle. Adjustment of tool edge. More care than for usual tool tips. Sideways adjustment. Operation. Stopping the spindle. Stop operation when the tool edge shows sign of chipping, and when vibrations are caused. Feed should be steady. Light oil emulsion some-times applied mainly for chip removal. Metallic materials. Non-metallic materials. Cutting speeds. Feeds 0.0005 to 0.004 in. per rev. Depth not more than 0.008 to 0.025 in. Tools with ball support can sustain cutting depths up to 0.06 in. Economical selection of cutting speeds given in table. Surface finish obtained.

Tools for High-Speed Planing, by J. M. Walter. (*The Machinist, 4th March, 1944, Vol. 87, No. 46, p. 90, 6 figs.*).

Difficulties in use of carbide-tipped tools for planing at high speeds have been successfully overcome by careful analysis of cutting conditions for different applications, including feed and speed, depth of cut, and the nature of the job. Thus more efficient cutting action and reduced tool cost is possible in spite of the intermittent cutting action and heavier cuts involved in most planer work. However, this is possible only with strict adherence to the necessary tool shape, and rake and clearance angles determined for a particular job. Also important is the proper control of the manufacture and maintenance of the tool, which preferably should be ground in the tool department and not by the planer operator. Details of the tools used for planing castings are shown. Feed should be uniform. Idle time of the planer can be reduced materially if work is set up on a separate plate like the one shown, while the planer is being used for other operations. When one job is finished, it is a simple matter to inter-change transfer plates on the table of the planer. Repack after roughing.

The Economical Use of High-Speed Steel, by J. Farmer. (*Machinery 9th March, 1944, Vol. 64, No. 1639, p. 259, 1 figs.*).

Stock sizes. Economical section. Standardization of tool forms. Grinding. Cutting-off . Economical length. British pre-war high-speed steels. Composition and heat-treatment. British war-time high-speed steels. Composition and heat-treatment. Selection of pre-war and war-time U.S.A. high-speed steels. Composition. Forging and annealing of high-speed steel. Machine-tool design effects. Correct use of the various grades.

High-speed Steel Tipped Tools and Tool Grinding, by J. Farmer. (*Machinery, 16th March, 1944, Vol. 64, No. 1640, p. 287, 4 figs.*).

The butt-welded tool. Grinding. The brazed or tipped tool. Common forms. Shanks. Preparation of the tips. Packing blocks for milling tool tips. Grain sizes and hardness grades of grinding wheels. Brazing. Tempering. Grinding. Tools for brazing. Grinding wheel recommendations. Re-conditioning roller-type milling cutters.

Increasing Tool Life by Better Tool Finishing, by V. H. Ericson. [*Mechanical Engineering,* (*U.S.A.*), *February, 1944, Vol. 66, No. 2, p. 107, 9 figs.*].

Investigating tool-grinding procedure. Tool-finishing operation devised. Sharpening gear cutters on fine-grit wheel. Advantages of keener edge and high surface finish.

Ardoloy Drawing Dies. (*Machine-Tool Review, January-February, 1944, Vol. 32, No. 189, p. 9, 12 figs.*).

The qualities of Ardoloy make it particularly suitable for drawing dies. The design of the dies and the method of holding them in the die boxes ensure sharp, square corners. Surface finish is also greatly improved. Dimensions of solid Ardoloy drawing dies.

Drilling Diamonds for Wire Drawing Dies. (*Industrial Diamond Review, March, 1944, Vol. 4, No. 40, p. 65, 3 figs.*).

Dies for drawing wire in tungsten, molybdenum and various other metals down to 0.001 mm. Process employed.

Electrochemical Removal of Broken Tools, by J. L. Bleiweis and A. J. Fusco. (*Metals and Alloys, November, 1943, Vol. 18, No. 5, p. 1075*).

Steel taps, studs, drills, etc., broken off in Al parts are removed by electrochemical treatment in saturated ammonium sulphate solution, making the tool the anode. There is no corrosive effect on the Al, nor any loss of tolerance. Details are given of a laboratory apparatus and a commercial set-up. To remove broken tools from Mg. alloys the electrolyte is 48-52% hydrofluoric acid with addition of inhibitor to retard corrosion of the Mg. Very short notes are appended giving methods for straight chemical removal of steel and Cu alloy tools from Al, Cu alloys, Monel and stainless steel.

(*Communicated by the British Non-Ferrous Metals Research Association*).

STANDARDISATION.

Universal Screw Threads, by H. F. Atkins. (*Machinery, 2nd March, 1944, Vol. 64, No. 1638, p. 241, 2 figs.*).

Comments and proposals. Form. Whitworth. Metric and U.S.A. Proposed alternative. Pitch. Limits.

Geometrical v. Arithmetical Progression. (*Machinery, 30th March, 1944, Vol. 64, No. 1642, p. 349, 5 figs.*).

Speed characteristics in arithmetical progression. Speed characteristics in geometrical progression

SURFACE, SURFACE TREATMENT.

The Tomlinson Surface Finish Recorder. (*Machine-Tool Review, January-February, 1944, Vol. 32, No. 189, p. 23, 6 figs.*).

A mechanical type of instrument designed by Dr. G. A. Tomlinson of the National Physical Laboratory. An N.P.L. certificate is provided and a reliable and permanent standard supplied with the instrument enables it to be checked from time to time. An enlarged profile of the surface is recorded, usually at a magnification of 160x, on a smoked glass plate. This record is then projected or photographed with an optical magnification of 100x giving a total of 16,000x. A point records the cross-sectional profile of the surface by scribing through a light smoke film on glass plate.

The Fundamentals of Chemistry for Electroplaters, Parts I and II, by S. Glasstone. (*Monthly Rev. Amer. Electroplaters' Soc., November-December, 1943, Vol. 30, Nos. 11, 12, p. 995, In progress*).

The first two of a new series of articles on chemistry in relation to the principles and practice of electroplating. Part I deals with elements and compounds and Part II with the laws of chemical combination.

(*Communicated by the British Non-Ferrous Metals Research Association*).

WELDING.

British Merchant Shipbuilding—Some Important Welding Developments, by R. B. Shepheard. (*Welding, March, 1944, Vol. 12, No. 4, p. 145, 13 figs.*).

Aspects of recent changes in merchant ship construction are dealt with by the author, including alterations to shipyard layout. The provision and installation of heavy duty welding equipment, high-speed procedures and modifications to hull form for fabrication are discussed. Butt welds in $\frac{3}{4}$ in. M.S. Plate.